

| REPORT DOCUMENTATION PAGE | | | | Form Approved OMB No. 0704-0188 | |
|--|-------------|-----------------------------------|-------------------------------|---|---|
| <p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p> | | | | | |
| 1. REPORT DATE (DD-MM-YYYY) 12-01-2006 | | 2. REPORT TYPE Final Technical | | 3. DATES COVERED (From - To) 7/2/2001-10/31/2005 | |
| 4. TITLE AND SUBTITLE A Proposal to Maintain the Gulf of Maine Ocean Observing System (GoMOOS) | | | | 5a. CONTRACT NUMBER | |
| | | | | 5b. GRANT NUMBER N00014-01-1-0999 | |
| | | | | 5c. PROGRAM ELEMENT NUMBER | |
| 6. AUTHOR(S) Bogden, Philip Pettigrew, Neal Irish, James Perrie, Will Roesler, Collin Thomas, Andrew Townsend, David Xue, Huijie | | | | 5d. PROJECT NUMBER | |
| | | | | 5e. TASK NUMBER | |
| | | | | 5f. WORK UNIT NUMBER | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Gulf of Maine Ocean Observing System (GoMOOS) 350 Commercial Street, Suite 308 Portland ME 04101 | | | | 8. PERFORMING ORGANIZATION REPORT NUMBER | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research Ballston Center Tower One 800 North Quincy Street Arlington VA 22217-5660 | | | | 10. SPONSOR/MONITOR'S ACRONYM(S) ONR | |
| | | | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) | |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release | | | | | |
| 13. SUPPLEMENTARY NOTES | | | | | |
| 14. ABSTRACT Funds submitted 2001 - 2005 to implement and sustain an ocean observing system for the Gulf of Maine have resulted in the organization widely known as GoMOOS. The technical program, implemented by scientists at University of Maine, Bigelow Laboratory of Ocean Sciences, Bedford Institute of Oceanography and Woods Hole Oceanographic Institution, includes 10 buoys collecting real-time observations of the ocean and atmosphere, predictive models of waves and circulation, testing of new technologies for monitoring nutrients and zooplankton, coordination of a variety of satellite measurements, a data management system to integrate all the data streams, a website to disseminate the information, a non-profit organization with over 40 member institutions representing the wide variety of users who need the data, and a headquarters in Portland, Maine that coordinates all the activities. | | | | | |
| 15. SUBJECT TERMS Ocean Observing | | | | | |
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON Philip S. Bogden |
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | 19b. TELEPHONE NUMBER (Include area code) 207-773-0423 |

Gulf of Maine Ocean Observing System
"GoMOOS, Inc."

Final Report – Award # N00014-01-1-0999

Submitted to the Office of Naval Research

January 25, 2006

Philip Bogden, CEO, Gulf of Maine Ocean Observing System

Neal Pettigrew, Chief Scientist, University of Maine

James Irish, Woods Hole Oceanographic Institute

Will Perrie, Bedford Institute for Oceanography

Collin Roesler, Bigelow Laboratory for Ocean Sciences

Andrew Thomas, University of Maine

David Townsend, University of Maine

Huijie Xue, University of Maine

OVERVIEW

Funds submitted 2001 - 2005 to implement and sustain an ocean observing system for the Gulf of Maine have resulted in the organization widely known as GoMOOS. The technical program, implemented by scientists at University of Maine, Bigelow Laboratory of Ocean Sciences, Bedford Institute of Oceanography and Woods Hole Oceanographic Institution, includes 10 buoys collecting real-time observations of the ocean and atmosphere, predictive models of waves and circulation, testing of new technologies for monitoring nutrients and zooplankton, coordination of a variety of satellite measurements, a data management system to integrate all the data streams, a website to disseminate the information, a non-profit organization with over 40 member institutions representing the wide variety of users who need the data, and a headquarters in Portland, Maine that coordinates all the activities.

The system works. Its hourly data have become routinely available via www.gomoos.org, NOAA weather radio, the National Data Buoy Center's dial-a-buoy service, television weather forecasters, the weather page of Portland Press Herald's website: www.maintoday.com, the buoy data pages at www.maineharbors.com, the buoy data page at www.fishresearch.org, the NDBC buoy-data pages, and others.

The data are in active use by a variety of end users including: monitoring water quality in Massachusetts Bays by the Massachusetts Water Resources Authority; monitoring environmental conditions relevant to aquaculture along the coast of Maine; marine research at the University of New Hampshire and other research institutions in the region; for safe marine operations by Penobscot Bay and Pilots Association; for sea-going activities of the United States Coast Guard who collectively represent one of the biggest users of the GoMOOS website, and for myriad other uses and users throughout the region. The applications are growing in both the public and private sectors. The system has filled a void as a public service utility.

The single observing system serves immediate needs for ocean and atmospheric conditions for safe marine operations; it provides long-term research-quality records that will be used to assess and predict fish stocks, detect coastal climate change; and it has been used to improve weather prediction and safety on shore. The weather forecast offices (WFOs) of the National Weather Service have been using GoMOOS data to adjust their forecasts and refine their skills.

The following testimonies come from an exchange between NOAA forecast officials, "The new GoMOOS buoy off Gloucester, especially, helped WFO Taunton staff this weekend to assess the building seas and alert officials to expected splash-over at time of high tide Sunday morning. Indeed, the increase to 19-foot seas at the Gloucester buoy heralded spotty flooding/debris along shore roads where the breakers sent spray over sea walls. The model forecast predictions alone would have underestimated the actual potential for damage and the needed emergency response. The benefits work in the other direction as well. In an earlier event this month, the slowness of seas to build at the Gloucester and Boston buoys helped us convey to emergency management (EM) officials with greater confidence that the coastal flooding would likely be less severe with little in way of structural damage. This again seems to say the in situ observations helped adjust the forecast to get better accuracy and a better skill score. It also talks to another important point: it convinced the EM that the effect would be less than forecast. We were able to lower the projected impact of the warning. Here we were able to limit the over-warning. That saved someone real money."

| | |
|---|-----------|
| GENERAL OVERVIEW | 5 |
| BACKGROUND..... | 5 |
| GoMOOS: FROM RESEARCH TO UTILITY | 6 |
| GoMOOS, INC. | 8 |
| MEMBERSHIP | 9 |
| GoMOOS HEADQUARTERS..... | 11 |
| WEBSITE | 11 |
| NOAA PARTNERSHIP | 13 |
| OUTREACH..... | 14 |
| THE NATIONAL SCENE..... | 14 |
| DATA AND INFORMATION MANAGEMENT | 15 |
| <i>Philip Bogden, CEO, GoMOOS.....</i> | <i>15</i> |
| DATA AND INFORMATION MANAGEMENT OBJECTIVES..... | 15 |
| THE OPERATIONAL SYSTEM..... | 15 |
| CLIENT SERVICES: THE TECHNOLOGY OF TURNING DATA INTO INFORMATION..... | 16 |
| CLIENT SERVICES: TRANSFORMING DATA INTO INFORMATION FOR USERS | 18 |
| BUOY AND CODAR PROGRAM..... | 20 |
| <i>Neal R Pettigrew, Chief Scientist, University of Maine.....</i> | <i>20</i> |
| BUOY DESIGN AND FABRICATION..... | 20 |
| THE BUOY ARRAY | 23 |
| DEPLOYMENT/RECOVERY ROTATION AND EQUIPMENT REDUNDANCY | 24 |
| PHOG WEBSITE, DATA ARCHIVE, AND QA/QC..... | 24 |
| BUOY SYSTEM PERFORMANCE..... | 25 |
| LONG-RANGE CODAR PROGRAM | 25 |
| BUOY AND CODAR PROGRAM PROGRESS SUMMARY..... | 29 |
| REAL-TIME OPTICAL DATA..... | 31 |
| <i>Collin Roesler, Bigelow Laboratory for Ocean Sciences</i> | <i>31</i> |
| CONTRACT DESCRIPTION | 31 |
| ACCOMPLISHMENTS AND STATUS | 31 |
| INSTRUMENTS | 31 |
| BIOFOULING..... | 32 |
| CALIBRATION/CHARACTERIZATION..... | 33 |
| PACKAGE DESCRIPTIONS | 34 |
| DEPLOYMENT/OPERATIONAL HISTORY | 34 |
| DATA HANDLING/DELIVERY..... | 35 |
| DATA PRODUCTS | 35 |
| DIFFERENCE BETWEEN CURRENT AND PROPOSED PROGRAM..... | 36 |
| TRANSITION TO AN OPERATIONAL OBSERVING SYSTEM..... | 36 |
| SYSTEM DESIGN..... | 36 |
| INSTRUMENT DESIGN | 36 |
| INSTRUMENT CALIBRATION AND CHARACTERIZATION..... | 36 |
| DATA QUALITY CONTROL AND ASSURANCE | 37 |

| | |
|--|-----------|
| DATA INTERPRETATION | 37 |
| EXAMPLES OF RESULTS | 38 |
| I. SEASONAL PHYTOPLANKTON BLOOMS IN THE GULF OF MAINE | 38 |
| II. GEOGRAPHIC VARIATIONS IN SEASONAL PHYTOPLANKTON BLOOMS..... | 39 |
| III. INTERANNUAL VARIATIONS IN PHYTOPLANKTON DYNAMICS..... | 40 |
| IV. SEASONAL PATTERNS IN ECOSYSTEM COMPOSITION USING HIGHER ORDER OPTICAL PRODUCTS..... | 41 |
| SATELLITE OCEANOGRAPHY | 45 |
| <i>Andrew Thomas, University of Maine</i> | 45 |
| OVERVIEW | 45 |
| WIND VECTORS (NASA's QUIKSCAT SCATTEROMETER)..... | 45 |
| SURFACE CHLOROPHYLL (SEA WIFS) | 46 |
| SEA SURFACE TEMPERATURES (NOAA's AVHRR)..... | 47 |
| GOMOOS PROGRESS REPORT: SATELLITE DATA SYSTEMS..... | 48 |
| CIRCULATION MODELING..... | 50 |
| <i>Huijie Xue, University of Maine</i> | 50 |
| THE GULF OF MAINE NOWCAST/FORECAST SYSTEM | 50 |
| DEVELOPED PRODUCTS | 52 |
| MODEL DATA ARCHIVE..... | 52 |
| GUI TOOLKITS | 52 |
| PUBLICATIONS | 54 |
| ONGOING AND PLANNED TASKS | 54 |
| REFERENCES | 55 |
| SURFACE WAVE FORECASTING IN GOMOOS..... | 56 |
| <i>Dr. Will Perrie, Bedford Institute of Oceanography</i> | 56 |
| ACCOMPLISHMENTS AND STATUS | 56 |
| WAVE MODEL | 56 |
| WINDS | 56 |
| WAVE VALIDATION | 57 |
| CASE STUDY: HURRICANE JUAN | 57 |
| NUTRIENT MONITORING - GOMOOS - FINAL PROGRESS REPORT | 65 |
| <i>David W. Townsend, Maura Thomas, and Megan Schiff, University of Maine</i> | 65 |
| INTRODUCTION | 65 |
| CASCO BAY NUTRIENT COLLECTIONS AND ANALYSES..... | 65 |
| ECOLAB IN SITU NUTRIENT ANALYZER LABORATORY CALIBRATION EXPERIMENTS... | 66 |
| PROGRESS/RECOMMENDATIONS | 66 |

General Overview

Background

The United States is working to launch a national coastal ocean observing system. NORLC's program unit, the National Ocean Partnership Program, has established a national coordinating office (known as Ocean.US) to put into place the framework of the system.

The Commission on Ocean Policy, the President's Ocean Action Plan, the Pew Oceans Commission, Congress, and many studies and government ocean advisory groups call for implementing a sustained Integrated Ocean Observing System (IOOS). Ocean observing is the essential first step to improving our understanding, forecasting, stewardship, and use of the oceans and our US coastal waters, including the Great Lakes.

Deployment and operation of an IOOS will address 7 principal goals:

- 1) improve the safety and efficiency of marine operations,
- 2) improve prediction of natural hazards (including tsunamis and storm surges) to reduce resulting damages and costs,
- 3) improve predictions of climate change and its socio-economic consequences,
- 4) improve national security,
- 5) reduce public health risks,
- 6) more effectively protect and restore healthy ecosystems, and
- 7) sustain and restore living marine resources.

Returns are expected in maritime safety and efficiencies for shipping, fishing, fresh water source protection in the Great Lakes, aquaculture, energy, tourist, and other industries; search-and-rescue; national security; and monitoring and clean-up of discharges and spills to ocean waters.

The technology that will drive the system is still evolving, but many requirements are available and tested. This technology has proven its value in efforts ranging from the vast Tropical Ocean Atmospheric Array in the equatorial Pacific to the regional scale multipurpose GoMOOS array and finally to the small but intensive test beds such as LEO-15 off the coast of New Jersey and the Martha's Vineyard Coastal Observatory off of Cape Cod. These and many other systems are employing combinations of satellite technology, *in situ* measurements from moored buoys, autonomous underwater vehicles, and shipboard surveys. Most are single purpose and/or short-term research projects, but they are successfully collecting meteorological, physical oceanographic, and, to lesser extents, chemical and biological observations of the oceans. Provided that the observations can be continuous and ongoing -- the fundamental purpose of the movement toward a sustained coastal ocean observing system -- they will be the foundation for increasingly sophisticated models that can predict events, from the recruitment of fish stocks to the trajectory of oil spills.

As conceived by the intellectual leaders in the movement toward a comprehensive coastal ocean observing system, the system will build on the many fragmentary pieces already in place. Special attention is being given to three basic components of the system: the collection of observations, the communications and management of data, and the translation of the data into useful products through data assimilation and analysis.

However, these technical pieces of the system will not themselves create the system. An institutional arrangement is needed to put the pieces into place, govern the system, gain the credibility of national governments and other sources of sustained funding, and assure that the system will meet the day-to-day needs of users who depend on the coastal ocean for their livelihoods and well-being.

GoMOOS: From Research to Utility

The broad outline leaves a lot of room for the design of the regional entities that will make up the national system. And here the challenge is substantial, because there is little experience or language in the world of oceanography to describe what these entities might look like and how they might be governed. The goodwill and collegiality that binds researchers during research projects will not meet the requirements of a sustained operational system. A coordinated national system needs more than the endurance, vision and independence of a few tenured stalwarts who support their systems on research grants. The only language available to the research community is that of the research world. As a result, almost all of the existing ocean observing systems are based on a research paradigm. In that paradigm:

- The system is led by a scientist based at an academic or other scientific institution;
- The principal purpose of the observations is the discovery of knowledge;
- The principal customers of the system are researchers, and the decisions of what to observe, and how, brings the broad range of users in as an afterthought;
- The systems depend on a series of short-term, competitive grants;
- The infrastructure vanishes after 3-5 years.

When the Gulf of Maine Ocean Observing System was first conceived, it was conceived in this language. But soon the founders realized that a different paradigm was needed. The research model was limited especially in three ways. First, existing research organizations in the Gulf of Maine region naturally were suspicious of what appeared to be the creation of a competing organization, one that would survive only if it ate into the same resources upon which existing universities and research labs depend. It became clear that the Gulf of Maine region – already blessed with renowned marine research organizations and universities – did not need another one. Rather, what the region needed was infrastructure that would enable the existing organizations to pursue their work more effectively.

Second, under the research model, the assets of the system – the moored buoys and other equipment -- would be deployed to answer research questions. It would be assumed that the observations and predictive capacity thus gained would be useful to other sectors as well, including shipping, the fisheries, search and rescue, and so forth. But such spin-off benefits would be incidental, not primary. Yet, to sustain long-term support and funding requires that many user groups see the system as essential to them, designed specifically to help them solve their day-to-day problems in real time.

Third, the research model did not provide a path to operations. It was difficult to project how it would evolve into a “24-by-7” real-time operation, when such a mode is inconsistent with the mission and objectives of the principal investigators and their academic or research institutions. Whereas a successful research project can leave all its results until publication at the end of the grant period, a useful operational system becomes one upon which users depend for timely delivery of information. The operational system cannot go away on weekends, it cannot wait for quality control, and it cannot become secondary in priority to some other project. Users, including researchers, desperately need data records that exceed the duration of typical research grants, but many users also need the timely delivery of quality information. The maintenance requirements of such a system provide unfamiliar and costly demands on the research world.

Thus, a different model was required. The founders of GoMOOS turned to the model of a utility cooperative. Its paradigm is, in many ways, the converse of the research model. Yet, paradoxically, the research community stands to be one of the biggest users and beneficiaries of the system. In the new paradigm:

- Rather than a research endeavor that creates its own single-purpose infrastructure, GoMOOS is an infrastructure project – not unlike the deployment of a telecommunications system or an electrical grid – that will benefit many users, including researchers.
- Rather than a mission defined solely by the pursuit of knowledge, its mission includes the collection of data, creation of data products, and dissemination of useful information upon which many, including researchers, can rely for a variety of purposes.
- Rather than targeted solely to the needs of a small group of researchers in search of knowledge about a single process, it is targeted to the entire ocean science community, along with an array of users whose needs can be determined by traditional market analysis.
- Rather than led by a scientist burdened with managerial responsibilities, it is led by a chief executive officer who understands researchers’ needs and who relies upon a team of scientists who provide the technical expertise to design, implement and oversee the system.
- Rather than a research organization whose independent projects are governed by principal investigators, it is a service organization governed by a board of directors, with contracts awarded to scientists who can design and deploy the system according to specifications needed to meet its multi-purpose mission.

- Rather than burden individual scientists with the responsibility of obtaining funds to support the infrastructure, it becomes the purpose of the board of directors to collectively acquire the funds.
- Rather than rely on short-term competitive grants, it requires long term line-item funding to provide the foundation for sustained operations.

GoMOOS, Inc.

The Gulf of Maine Ocean Observing System (GoMOOS, Inc.) is a nonprofit corporation. It is a membership organization whose charter members came together to create a system that speaks to the needs of each – whether to facilitate research, manage fisheries, monitor water quality, or improve the safety of mariners. The breadth of interest in a system is represented by the breadth of sectors among the charter members: shipping companies and services, universities, colleges, and marine research organizations, fishing concerns, water and resource management agencies, petroleum industry, technology companies, and public service organizations like aquariums.

Although GoMOOS is a membership organization, the observations gathered and the information products developed from it are made available to the public on a free and open basis. At this time, membership is motivated not by the prospect of gaining access to proprietary information, but rather by a self-enlightened interest to create a system that otherwise would not exist, a system to collect observations vital to individual corporate, research, management, or educational needs, a system of which they would otherwise be deprived because no one else is going to do it. In this sense, the system is a cooperative utility.

The purpose of having GoMOOS incorporate as a 501(c) 3 was to allow the participants to act collectively like an individual, to take on fiduciary responsibilities and to assume liabilities. The corporate structure also ensures a plan of succession, insulating the system from departures or retirements of key individuals. This is essential to sustained “24/7” thinking.

The GoMOOS Board of Directors has clear responsibilities. Consistent with those responsibilities, the Board and the organization work to obtain funds to develop and operate the system. This is a fundamental departure from the research paradigm where the scientists obtain the funds. Founding members chose to have institutions represented on the Board because institutions have the staying power for an operational system, and the organization has collectively more power than any of the individual institutions. The individuals on the board represent their institutions. When scientists are given decision-making authority for their institutions they may represent their institutions on the Board. However, the organizational structure puts scientists in roles that capitalize on their greatest strengths, namely, designing and implementing the system.

The so-called Science Team, chaired by the GoMOOS Chief Scientist, comprises a collection of research scientists under contract to GoMOOS. To date, the science team has implemented and operated the entire technical program. Future vendors for

operations may expand to include outside contractors, other institutional entities, or federal agencies. In either case, GoMOOS will keep a core set of scientists involved in the technical program to provide expert high-level oversight where appropriate.

The Chief Executive Officer (CEO) of GoMOOS--a scientist devoted to running the organization--reports to a Board of Directors. The CEO, the Chief Operating Officer, and Chief Scientist work with the Science Team to create budget recommendations. These recommendations are subject to final approval by the Board.

GoMOOS headquarters maintains a small staff (7 people), with the bulk of the operational program historically being implemented under contract to member institutions. Two key activities remain the responsibility of GoMOOS headquarters: data management and information-product development.

For data management, GoMOOS uses guidance from its CEO and Director of Program Development to work with technical staff who develop and maintain a centralized database that coordinates and archives data and data products from the various components of the technical program. The data management system assures that the research quality data retain their value long into the future for all potential users. A single centralized database for the organization holds all the information relating to the technical program so that any user knows not only what kind of data was collected, but also how it was collected and how it was processed. This kind of data documentation becomes especially important with pre-operational activities for which data collection standards have yet to be created.

For the second key activity, namely, development and dissemination of useful information, the process uses the CEO, Director of Program Development, and Chief Operating Officer. Their associated responsibilities collectively assure that the system is being used effectively outside the research community. This requires two basic ingredients: (1) an understanding of the needs of users in the Gulf of Maine developed through Board interactions and ongoing market research activities coordinated by GoMOOS headquarters, and (2) the judgment and skills of the Science Team in creating a system that can best meet those needs. Information development is an ongoing process within GoMOOS.

Membership

Membership in GoMOOS is open to any institution interested in supporting GoMOOS and its mission. All members pay annual dues, which are calculated on a sliding scale, based on the institution's marine revenues. GoMOOS membership is now over 40, and continues to grow. Membership includes a diverse group of research institutions, fishermen associations, non-profits, government agencies and private companies. Current membership includes private industry, research institutions, government agencies, and non-profits.

Table 1: Current GoMOOS Membership:

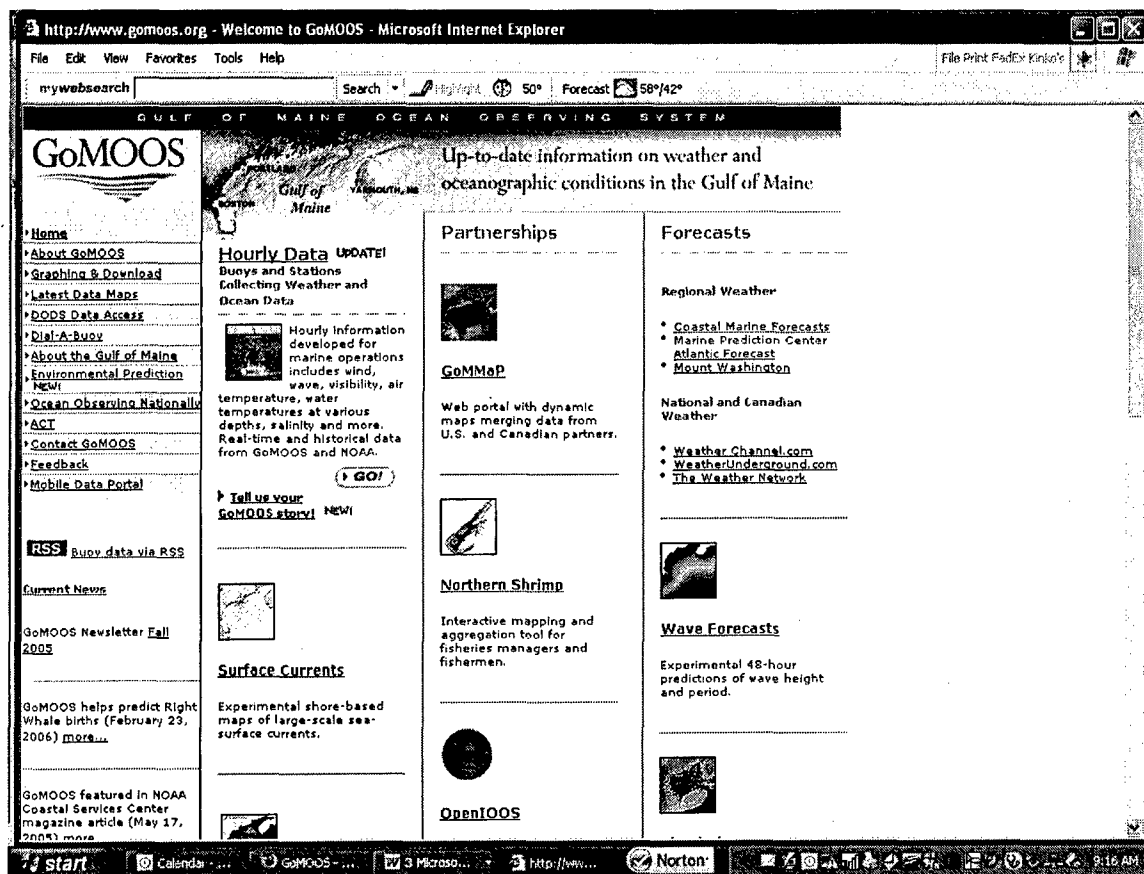
| | |
|--|---------------|
| Atlantic Pilotage Authority | Nova Scotia |
| Bedford Institute of Oceanography | Nova Scotia |
| Bigelow Laboratory for Ocean Sciences | Maine |
| Bowdoin College | Maine |
| Durand and Anastas Environmental Strategies | Massachusetts |
| Eastport Port Authority | Maine |
| Federal Marine Terminals | Maine |
| Gulf of Maine Research Institute | Maine |
| Gulf of Maine Program – CoML | Maine |
| Horizon Marine, Inc. | Massachusetts |
| Island Institute | Maine |
| Maine Dept. of Marine Resources | Maine |
| Maine Lobstermen's Association | Maine |
| Maine Maritime Academy | Maine |
| Maine Port Authority | Maine |
| Maine State Planning Office | Maine |
| Massachusetts Lobstermen's Association | Massachusetts |
| Massachusetts Office of Coastal Zone Mgmt | Massachusetts |
| Massachusetts Water Resources Authority | Massachusetts |
| MetOc – Halifax | Nova Scotia |
| MIT Sea Grant | Massachusetts |
| National Marine Fisheries Service | Massachusetts |
| National Undersea Research Center | Connecticut |
| New England Aquarium | Massachusetts |
| NOBSKA Development Corp. | Massachusetts |
| OEA Technologies, Inc. | Nova Scotia |
| Penobscot Bay & River Pilots Association | Maine |
| Portland Pipe Line Corp. | Maine |
| RD Instruments, Inc. | California |
| Rutgers University – IMCS | New Jersey |
| St. Andrews Biological Station | New Brunswick |
| Saint John Marine Pilots | New Brunswick |
| Satlantic Incorporated | Nova Scotia |
| Stellwagen Bank National Marine Sanctuary | Massachusetts |
| United States Geological Survey – Woods Hole | Massachusetts |
| University of Maine | Maine |
| University of Massachusetts – SMAST | Massachusetts |
| University of New England | Maine |
| University of New Hampshire | New Hampshire |
| University of Rhode Island – GSO | Rhode Island |
| Woods Hole Oceanographic Institution | Massachusetts |

GoMOOS Headquarters

Philip Bogden, former academic research oceanographer, was hired at the Chief Executive Officer in February 2002, to manage and oversee the organization. An office was established in Portland to oversee and manage partner contracts, Board relations, membership development, user outreach, website design and data management.

Website

Figure 1: GoMOOS Home Page (partial view)

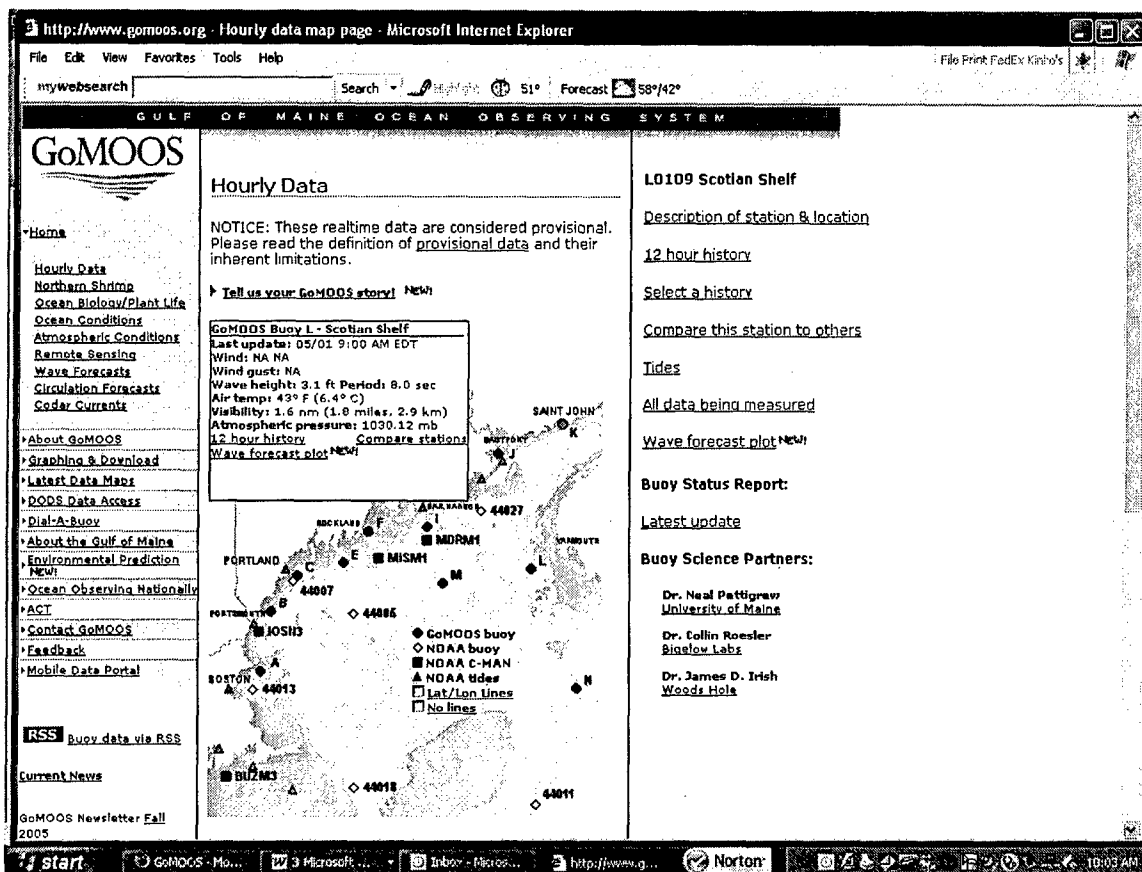


GoMOOS's primary interface to the world is through the Internet. For nearly five years, real-time data on the atmospheric and oceanographic conditions of the Gulf of Maine have been available on at www.gomoos.org.

The website changes and expands continually with development of new information products as GoMOOS responds to user needs. The web design incorporates the ideas and suggestions gleaned from a "discovery" process with mariners (shippers, fishermen, recreational boater, etc). The discovery process is a standard market-research tool for product development, in this case applied to web development. During the process users are asked questions about how they make decisions, the kinds of technology that they

use, and the kinds of information that they use, day to day. They are not asked direct questions about website design. For the first website release, GoMOOS interviewed over a dozen fishermen, shippers, harbor pilots and boaters as part of the discovery process, and a similar amount during prototype testing. Key elements in the website design included the need for simple graphics that load easily on dial-up connections, the importance of weather information and the need for information when at sea, browser compatibility and the need to avoid browser plug-ins and special software downloads.

Figure 2. GoMOOS Buoy Data page created for mariners



The interface for real-time buoy data (above) emphasized the mariners' needs for present conditions. They wanted quick access to multiple-buoy comparisons, charts of the 12-hour history, navigational charts showing the buoy locations, etc. All of these services are in easy reach from the "buoy data" page at www.gomooos.org.

Additions to the website are following a thematic approach. The objective is a theme-based catalog of GoMOOS data products, which will serve as the basis for continued product development. The catalog presents a comprehensive look at specific topics such as oceanographic conditions, atmospheric conditions, environmental health, and water quality. The oceanographic and atmospheric conditions products were launched to combine remotely sensed data with in situ measurements to provide users with a

comprehensive look at the GoMOOS information on the theme. Biological data and wave modeling is planned for December; water quality will follow in February.

NOAA Partnership

GoMOOS has been working locally with the Weather Forecast Offices to make data available for their use. As a consequence, GoMOOS data has become part of the regular NOAA Maine Weather Radio broadcasts in the New England Region.

GoMOOS also established a partnership with NOAA's National Data Buoy Center (NDBC), which led to incorporation of GoMOOS data into the National Weather Service forecasts and the NDBC dial-a-buoy service. Dial-a-buoy has been especially popular with professional mariners who need access to the information when they are at sea and away from their computers. This service has been well received and the GoMOOS-distributed dial-a-buoy instruction cards are now in their second printing.

In late 2005 GoMOOS also introduced the website in PDA format for persons using handheld devices to access the data.

With GoMOOS data as part of the NWS, local television weather forecasters were able to start getting forecast products that included GoMOOS data from their professional weather providers. As a result, GoMOOS data started becoming a regular feature on the local television in the summer of 2003.

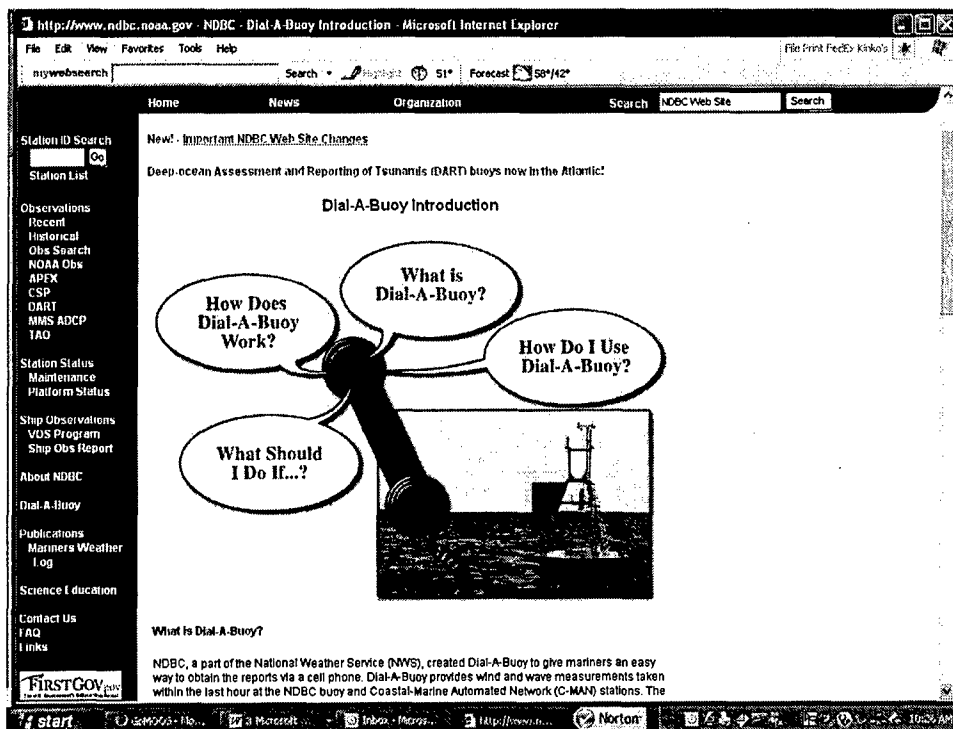


Figure 3: NOAA National Data Buoy Center Dial-A-Buoy Page

Outreach

There are other examples of GoMOOS data becoming a regular part of peoples' lives. One of the major newspapers in Maine, the Portland Press Herald, now provides GoMOOS information on their webpage. The hourly updates for the Casco Bay buoy are provided directly on the page and links directly to the GoMOOS data page for additional information.

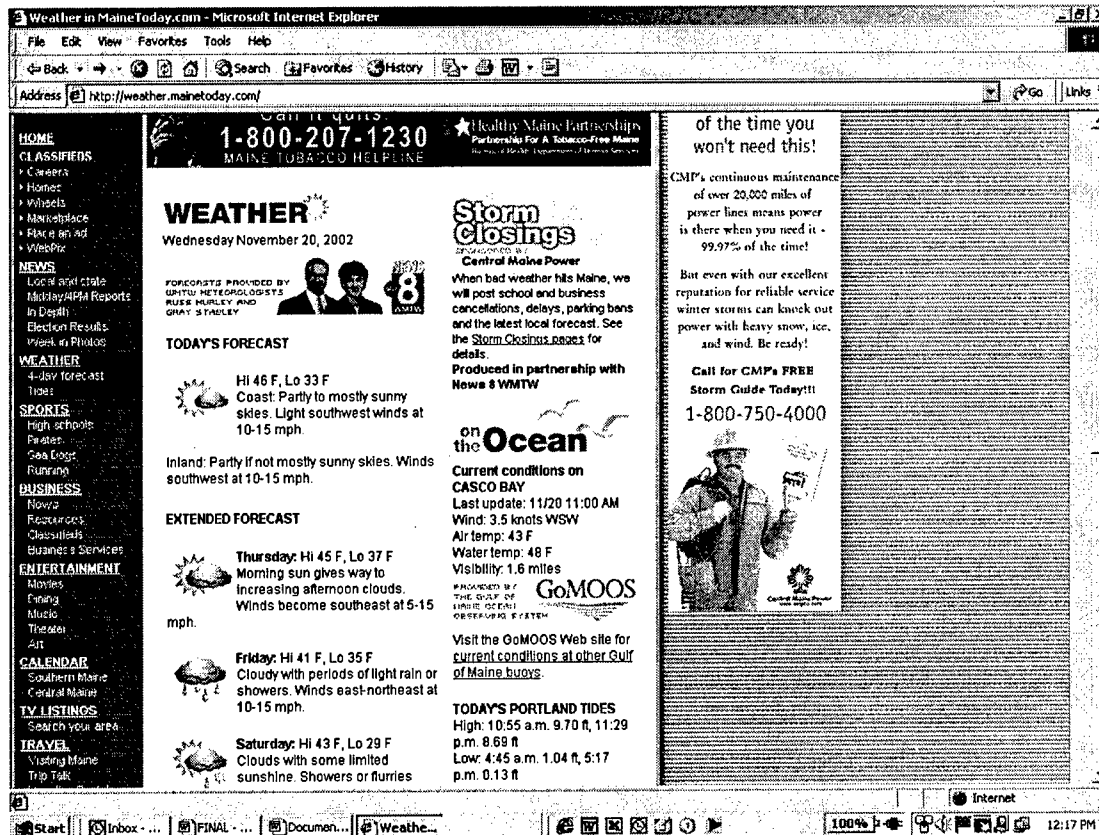


Figure 4: Portland Press Herald website weather pages with GoMOOS data presentation

GoMOOS has been featured on several different Maine Public Radio segments, and on public television. QUEST is an educational science show on Maine Public Television. As a companion to the television show, the producers developed a high school curriculum. The curriculum focuses on the GoMOOS section of the show and instructs teachers how to access GoMOOS information from the web to use in their classrooms.

The National Scene

GoMOOS contributes to work with Ocean.US, the US GOOS Steering Committee, the U.S. Commission on Ocean Policy, and the National Federation of Regional Associations (for Ocean Observing) and other nascent regional systems to help implement the national federation of regional ocean observing systems as envisioned by the National Ocean Research Leadership Council and its program offices.

Data and Information Management

Philip Bogden, CEO, GoMOOS

Data and Information Management Objectives

The originally proposed GoMOOS information management system had several operational objectives, including:

- Design that serves both the immediate and future missions of Ocean Observing Systems,
- Flexible and modular structure that is compatible with current systems and amenable to evolution as information technology changes,
- Capability to provide users with search and discovery capabilities, and to provide seamless access to any information within the system, and
- Capability to integrate with other Ocean Observing Systems, with historical data archives for the Gulf of Maine, and a range of heterogeneous distributed sources.

These objectives describe the system that has been put into place to date. The objectives have been augmented in one important respect:

- The system assures that the research quality data will retain their value with a centralized database that holds all the information relating to the data acquisition system (buoy program) allowing any user to know not only what kind of data were collected and their values, but also how they were collected and how they were processed.

The Operational System

The original proposal identified the following specific design criteria:

1. Client/server architecture that manages data through a data warehouse that supports the dissemination of GoMOOS data and products over the Internet.
2. Integration step where data are structured, normalized, checked for inconsistencies and derived products created. The warehouse itself must be capable of storing heterogeneous data types including structured data plus text, imagery, video, and potentially audio.
3. Metadata catalog to provide a frontline interface to the user, including summaries of the data contained in the warehouse, brief entries for data sets or observations that note times, spatial locations, and depths. Additionally the catalog may include thumbnail versions of images, histograms, time series plots, model descriptions and images of model results. The catalog thus contains abstract representations of the full data sets contained in the warehouse.
4. The development of the data warehouse will involve development of warehouse services and metadata services. Warehouse services will be built on top of a commercial database system that supports spatial and temporal data types and indexing over these data types.
5. Data warehouse server that supports easy loading of new data sets, multiple indexing over the data sets and summaries of new data that can be passed up to the metadata catalog. The warehouse server must support potentially large numbers of users with optimal query performance across a range of query types.

The data management system uses criterion #1—a client/server architecture—for getting from data sources to the users. Criterion #2—data-integrity checking—has been partly implemented. The underlying objective is to store buoy data in the most “raw” form available and then maintain the software that can be used to create data products from that raw data. This way, any post-processing, calibration, or re-calibration can be documented in the software, which is stored as metadata. This means recalibrated values can be easily recomputed when the new calibration coefficients are determined. This strategy accommodates both “24/7” needs to get data out quickly, and long-term research goals to get the most accurate values. The latter often requires post-hoc analysis due to recalibration of instruments when they return from sea, etc. As a result, data presented in real-time need not be the same as data archived in the database for later use. Either way, the database provides a detailed record of everything done to obtain the available data.

Criterion #3—the metadata catalog—is nearing completion for buoy data. A new 3rd database schema has been created to accommodate the metadata for other data types. Criterion #4—metadata services built on top of a commercial database for use with spatial data—has not been adopted, at least not yet. As mentioned above, open-source (freely available) database software serves our purposes.. The primary impediment to moving to the existing system to commercially available software (such as Oracle) will be the cost of software licenses.

Criterion #5—server scalability and efficiency—has been implemented in the current generation database that serves www.gomoos.org. This database developed from the requirements for storing information in the buoy program. The data schema can accommodate any kind of scalar time-series data obtained at a fixed location. New data types, instrument types, locations, etc., can be added without the need for an additional table in true relational database style. The schema easily accommodates queries by spatial location, time, data type, mooring, instrument type, etc. We use the schema to store and re-display data from NOAA buoys, and C-MAN stations. These 10 tables can accommodate any kind of instrument in the moored buoy array and unlimited data types.

Client Services: The Technology of Turning Data into Information

Progress on the technological infrastructure to create information products will be reviewed in relation to the requirements listed in the original GoMOOS proposal and reproduced here:

- A. Viewing of now-time conditions: Graphical displays of near real time conditions for measured variables: sea surface temperature, wind speed, ocean color, surface currents, scatterometer winds, and buoy data will be made available. Users should be able to easily navigate and request the variables of their choice and zoom and pan functionality will be supported for these displays.
- B. For mariners, or others without access to computers and the Internet, the latest buoy data should be available via phone from a system akin to the NDBC's Dial-A-Buoy system. The buoys and data types will be selectable via a menu and a computerized voice will read a text message with the latest data values.

- C. Downloading of now-time data with the Distributed Oceanographic Data System (DODS). DODS is a client-server system that uses http as the low-level communication protocol.
- D. Searching the archive: In addition to supporting display and download of now-time data, users should have access to the GoMOOS archive through flexible and efficient search and retrieval. Search functionality should allow for search over the spatial dimension (e.g., near shore, Massachusetts Bay, a region specified in latitude and longitude, depth, etc.), the temporal dimension (e.g., data from last year, from last January, from last summer, etc.) and topical criteria (e.g., sea surface temperature, currents, dissolved oxygen).
- E. Browsing the archive: Users need the capability to quickly browse the archive for information of interest. Browsing will be supported by summary information on the archive contents. Thumbnail versions of images stored in the metadata catalog will be accessible to users to quickly check for presence of features of interest or presence of cloud cover.
- F. The GUI component will consist of a web-based front end developed in Java for platform independence. The Java front end will provide intuitive access to the warehouse services that support query, browse and retrieval of information from the archive.

Services A and B—viewing of real-time conditions and dial-a-buoy—have been implemented at www.gomoos.org. Dial-a-buoy was obtained in collaboration with NOAA's National Data Buoy Center (NDBC). As a result of the NDBC collaboration, GoMOOS data are ingested into the National Weather Services AWIPS system, so GoMOOS data have become part of the national forecast system. Moreover, commercial weather providers, such as WSI Inc., are creating data products for forecasters such as Dave Santoro, the weather forecaster for a local television station in Portland, Maine. And GoMOOS buoy data have become regular components of NOAA's weather radio broadcasts.

Service C—DODS access—to the GoMOOS database has been implemented (see www.gomoos.org/dods/). DODS has been renamed OPeNDAP and GoMOOS has participated in a pilot project to implement OPeNDAP at partner organizations.

Service D—metadata search capability—was built into the database schema presently in use at www.gomoos.org. All that remains to fully implement D is creation of a user-friendly interface. We view the notion of “useable” interfaces as an ongoing activity that requires interactions with users.

Service E—browsing interface—ties in closely with Service D. With regard to Service F—Java for platform independence—we use platform-independent software (the stated advantage of Java) as a matter of course and rely heavily on Perl and PHP, but we use relatively little Java.

Client Services: Transforming Data into Information for Users

In the fall of 2001, GoMOOS began the first element of a four-pronged strategy developing useful information products. A 6-month-long process led to the implementation of the real-time buoy data pages at www.gomoos.org. The entirely new web site was designed with mariners in mind, and involved a series of interviews with fishermen, harbor pilots, and recreational boaters. This "market research" and "discovery" process, along with extensive prototype testing, resulted in the user interface for real-time data that can still be found at the GoMOOS website. The interface has been linked to some private web sites, including the weather pages at www.maintoday.com (the Portland daily newspaper), and the buoy-data pages at www.maineharbors.com (used by recreational boaters).

Under our first ONR grant, we also began a yearlong effort to develop a web-based thematic and annotated catalog of GoMOOS data products. The strategy is to convert GoMOOS data into data products, provide some context for those data products, and then use those products as the basis for market-based information-product development. The first set of deliverables can be found by clicking on the "atmospheric conditions" and "oceanic conditions" pages at www.gomoos.org. This catalog builds on ideas that came out of the January 2002 Board of Directors retreat. There is no specific target audience for these products other than educated and interested non-scientists. This project has produced additional themes including "wave predictions," and "ocean biology".

Since its inception, GoMOOS, whose governing board includes a large complement of end users of ocean observations, has engaged users in understanding their needs. Through our user needs assessments GoMOOS learned that there was a widespread need among many users, some who were also data providers to be able to access and integrate multiple data sources from various organizations. In order to help meet this need GoMOOS helped form the Gulf of Maine Ocean Data Partnership (GoMODP) and is the host of the Partnership.

The GoMODP is comprised of 22 organizations that collect and manage environmental data within the Gulf of Maine and its watershed. Members include federal, state, provincial, university and research organizations in the US and Canada. The goal of the partnership is to make each partner's long-term datasets discoverable, accessible, and eventually interoperable through tools available on the internet. The partnership intends to use standards and protocols already in use by the various disciplines represented wherever possible. GoMOOS is helping to guide this effort and align it with other related efforts such as the Integrated Ocean Observing System and the National Water Quality monitoring Council.

To fulfill that GoMODP goal, partners have filled out detailed surveys regarding their data. This information, which is available to all partners, has greatly assisted in developing a strategy for achieving interoperability between the partners. Discovery metadata training and assistance have been provided by GoMOOS to partners to aid in establishing a common set of practices in the publishing of data through a number of interoperable standards based discovery web portals: Geospatial One-Stop, NASA's

Global Change Master Directory (GCMD), and the Canadian GeoConnections Discovery Portal. In addition a dedicated GoMODP discovery portal for the partnership's data sets has also been established by GCMD. The next phase of GoMODP development will be through a series of end-user oriented pilot projects whereby the partners are expecting to gain practical experience regarding the use of interoperable data access techniques like web services.

Achieving true data discoverability, accessibility, and interoperability without making the task overwhelming for the individual partners is challenging for such a diverse set of organizations. To reach this goal, the GoMODP develops a yearly work plan administered by a governing board and technical committee. The GoMODP continues to add members and hold annual meetings.

Buoy and CODAR Program

Neal R Pettigr w, Chief Scientist, University of Maine

Buoy Design and Fabrication

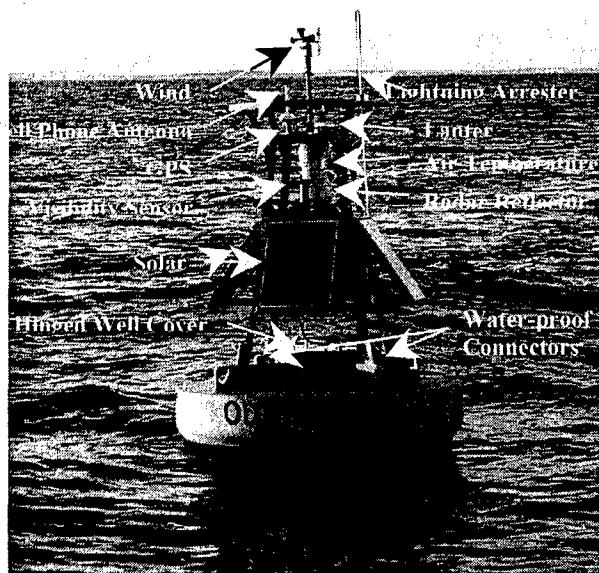
The central element of GoMOOS is the Ocean Data Acquisition Systems (ODAS) moored telemetering buoy array. The buoy array provides the platforms for the present and future suite of sensors that furnish the long-term, real-time data series that form the basis of the *in situ* physical, optical and bio-optical ocean observing in the Gulf of Maine. The design, production, and maintenance of these buoys are the primary tasks and the University of Maine's Physical Oceanography Group (PhOG).

PhOG has been designing and building ODAS systems designed specifically for the GoM environment since 1993. Since 1998, these buoys have been solar-powered and have had real-time data telemetering capability. The primary design tasks for the GoMOOS effort was to modify the buoy hull design so that the buoy could withstand the rigors of year-round offshore deployments in the Gulf of Maine, and to design a telemetry/data system that would provide for future sensor additions and maximum flexibility in sensor attachment/repositioning.

The design process started by combining telemetering and electronic characteristics of the PhOG buoy with some of the mechanical characteristics a buoy designed by Dr. J. D. Irish of the Applied Ocean Physics and Engineering Department at the Woods Hole Oceanographic Institution, and adding Seabird's inductive modem system for sending data up the jacketed steel mooring cable. The resulting design has been very successful in continuous operation since the summer of 2001.

Several incremental changes have been made to the buoy telemetry system. The initial system used analog cellular phones for the primary data transfer system and GOES satellite transmitters as a backup system. Each of these systems has its drawbacks, but in tandem they have provided reliable data telemetry approximately 95% of the time. During rough weather the GOES transmitters are prone to errors and cellular transmission cease at some locations during severe cold. The cause of the poor cold weather performance of the analog cellular link is unknown. We have tried several antenna configurations, but the problem has remained. We added Iridium phones to the two buoys that are too far from the coast for cellular coverage (buoys M and N) but have had to use iridium as a backup system because of the high expense of making 24 calls per day.

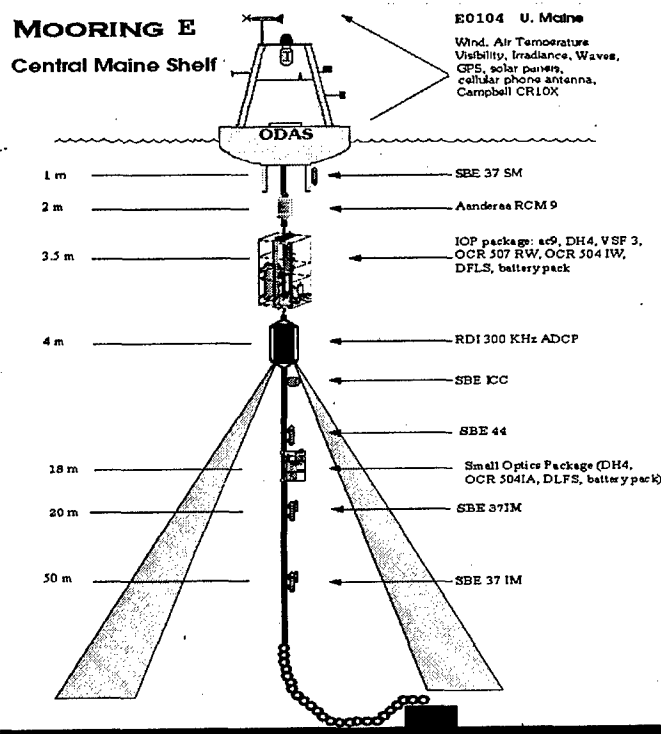
More recently we have switched three of the buoy locations to digital cellular phones that have a much higher data rate (buoys A, B, and C) in regions where this service is available. Thus far they have performed well and have the potential to handle the data from additional sensors in the future. We have begun testing Global Star systems as a more economical alternative to the Iridium.



The buoy superstructure carries a suite of meteorological sensors including wind speed and direction, air temperature, and visibility as well as the sea keeping components such as radar reflectors, lightning rod, solar panels, and antennas for the GPS and telemetry system. The data logger, buoy electronic and power systems are in the buoy well.

Data from the subsurface sensors are transmitted in two ways. Near-surface sensors are hard-wired to the waterproof connectors to the buoy data system, while deep instruments telemeter their data streams via

inductive modem technology. This technology allows data from up to 100 locations beneath the buoy to send data directly up the mooring cable with requiring direct electrical connection. This system, designed and marketed by Sea Bird Instruments Inc., is based on transformer technology, and inductively couples the sensors with the jacketed mooring cable. Sensors deployment depths may be changed at will, damaged sensors replaced, or sensors added without removing the buoy and mooring from the water.



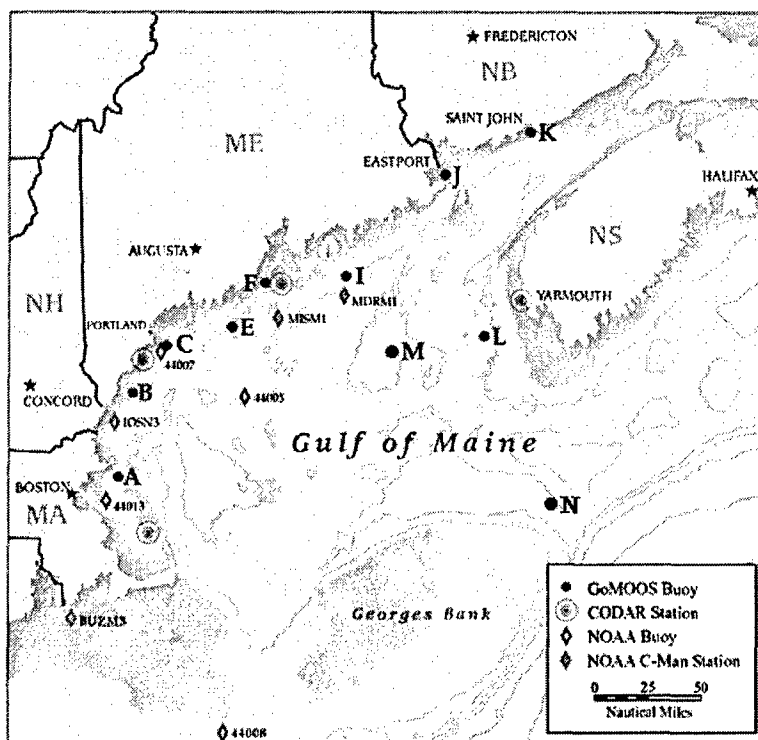
A schematic diagram of a GoMOOS mooring is shown at left. The example shown is one of the Central shelf moorings that are the most heavily instrumented. All the sensors between the surface and 4 m depth are electrically hard-wired to the ODAS. The deeper sensors and sensor packages send their data to the buoy data logger via the inductive modem technology.

Near-surface currents are measured at 2 m using an Aanderaa RCM 9 Doppler current meter. Since these CM's use acoustic Doppler technology, they are immune to the sometimes severe bio-fouling that occurs in the GOM at many locations. After a 6-month

deployment some of the near-surface sensors are recovered with several inches of blue mussel and other growth on them. The sound propagates through the fouling with little attenuation and the measurements are unaffected. Doppler current profilers are used to measure the current from 4m down to the near bottom. These instruments act as remote sensors and also are unaffected by the "blue mussel beards" that they often display after a six-month deployment. The optical instrument packages are described in the report by Dr. Roesler, and will not be discussed here. Seabird instruments are used to measure temperature and conductivity at fixed depths (coastal buoys 1m, 20m and 50 m; offshore buoys 1m, 20 m, 50m, 100m, 150m, 200m, and 250m). At some GoMOOS mooring locations the Seabird dissolved Oxygen sensor are coupled with seabird TC sensors. A complete list of the sensors deployed at each buoy location may be found websites <http://www.gomoos.org> or <http://gyre.umeoce.maine.edu>.

The GoMOOS buoy systems have some self-monitoring capability. All the buoys and are equipped with Global Positioning System (GPS) drift detection software, leak detection hardware, and power system auto check systems. The buoys check their own status and sends alarms if any of the parameters are out of range. These systems have proven very capable in thus far. Except for the first deployment at site L where the Canadian cellular system failed to connect, all incidences of buoys being dragged, breaking loose, or "shuffling" have been automatically detected and the buoys were reset with minimal loss of data and equipment.

The Buoy Array



Ten buoys locations have been occupied during the GoMOOS implementation phase. The full deployment started July 2001, and the entire array was initially deployed by September 2001. In the autumn of 2003 buoy K in Saint John NB Canada was pulled and it was refit for deployment at a higher priority site in the Northeast Channel in the spring of 2004. The GoMOOS buoy array is shown at left on the inset map as the red dots. As is evident from the map, the GoMOOS array has significantly expanded the number of locations at which meteorological and wave monitoring occur in the GoM. In particular, prior to the GoMOOS deployment wave measurements were made only in the GoM east of NDBC buoy 44005 on Cashes ledge. Buoy wind data in the eastern GoM region was similarly sparse, and these additions provided mariners, oceanographers and meteorologists alike with welcome data sources. NDBC has since added its first buoy in the eastern gulf off Jonesport, Maine.

The originally proposed GoMOOS array plan called for buoys of the design discussed above at locations B, E, I, L and K. As a cost-savings measure, nearshore locations were to be populated with smaller less expensive buoys that would not be designed to withstand the rigors of the open GOM. As the final buoy locations were chosen however, it became clear the many of the nearshore buoys would be subject to wind, wave and current regimes that closely approached those expected in the open GOM. As a result, it was decided that locations A, C, F, and K would all be better served by full-size GoMOOS buoys. Only J, in the Cobscook Bay, was judged to be significantly sheltered

waves and, to some extent, winds. On the other hand, site J was expected to experience the strongest tidal currents of all the GoMOOS buoy locations. In the final analysis, full-size GoMOOS buoys were deployed at all locations. Building the more expensive buoys was made possible through cost savings by efficient use of ship time and by using a smaller (and less expensive) ship than called for in the original proposal, cost sharing with other PhOG projects, and reduced personnel costs due to extremely high personnel motivation and productivity on part of the PhOG staff.

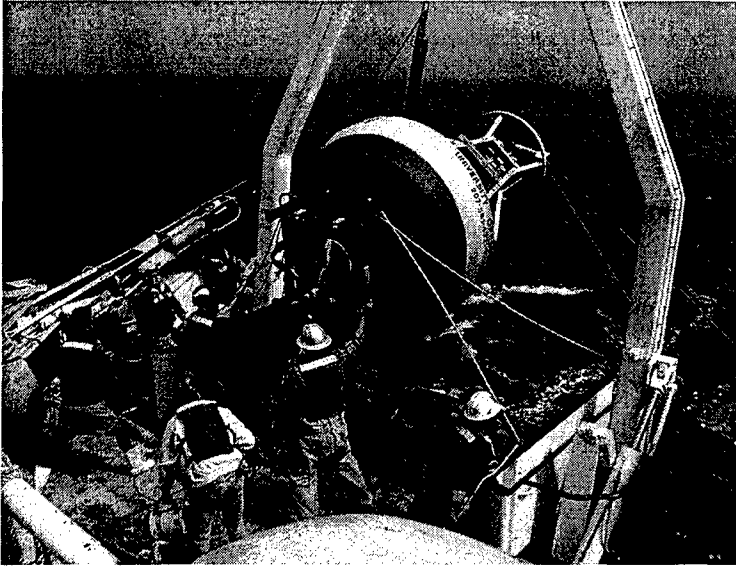
PhOG has recently designed a small GoMOOS buoy that is to be deployed in an estuary within the more sheltered waters of Casco Bay, Maine. This development was supported jointly by the State of Maine, ONR, and NOAA. The buoy electronics and hull are in the final assembly stage and it is expected the buoy will be deployed in the summer of 2006. The capabilities of the small buoy are the same as the full-size GoMOOS buoy except that it does not have the same potential for expansion nor the same sea-keeping abilities.

Deployment/Recovery Rotation and Equipment Redundancy

An operational decision was made to schedule service for the entire array twice per year rather than staggering the east and west maintenance that would have required four (shorter) service periods per year. The revised schedule saved approximately four man-months of effort in pre- and post- cruise preparations, and roughly 20% of the boat charter fees by reducing transit times. In order to realize these efficiencies, we needed to increase the sensor and buoy "redundancy" to 100%. Thus, we could leave port with a completely prepared replacement buoy and recalibrated sensors for each of the GoMOOS buoy locations. We believe that the 100% equipment redundancy has been a key to the success of the GoMOOS operational array. Our data return rate is approximately 90 %, and is significantly higher than any of the other nascent operational observing systems in the US. This success comes despite the fact that the GoMOOS system is significantly more complex and is in a harsh environment.

PhOG website, data archive, and QA/QC

Although PhOG was not funded in its contract to provide the GoMOOS website and data archive, PhOG produced both of these crucial functions so that the real-time data were delivered within hours of the first deployments. These services were as the interim solution until the official GoMOOS website became operational some months later. The PhOG website, database, and web download and plotting capabilities are still provided to scientific users through a link from the GoMOOS.org site. All data processing and QA/QC are still provided by the PhOG processing software on a continuing basis, and the data, are pushed to the GoMOOS website for distribution of derived data products to the public.



Buoy system performance

The GoMOOS buoy design has proven to be a good performer during the implementation phase of the GoMOOS program. In the last year, buoys exceeded 90% data return overall and exceeded average return rates from NDBC buoys in the region. Most of the data losses in the early years of operation resulted from mechanical coupling problems at the upper optics package.

We also had winter storm damage and vandalism at location L that resulted in poor data returns at that site. Additional ballast has been added to all buoys to improve buoy performance under the extreme wave conditions observed (max significant wave height 12 m). In addition, upgrades to the telemetry system and the real-time QA/QC have improved the reliability of the data telemetry system.

The second most significant cause of data loss was premature sensor battery failure in the surface current meters and some of the temperature/salinity packages. These problems were due to bad batteries and firmware problems that have been largely rectified by the manufacturers. We continue to have occasional failures that are related to power issues. They are due to a combination of substandard battery batches and out-of-spec power drains associated with the aging of sensor packages.

Long-range CODAR Program

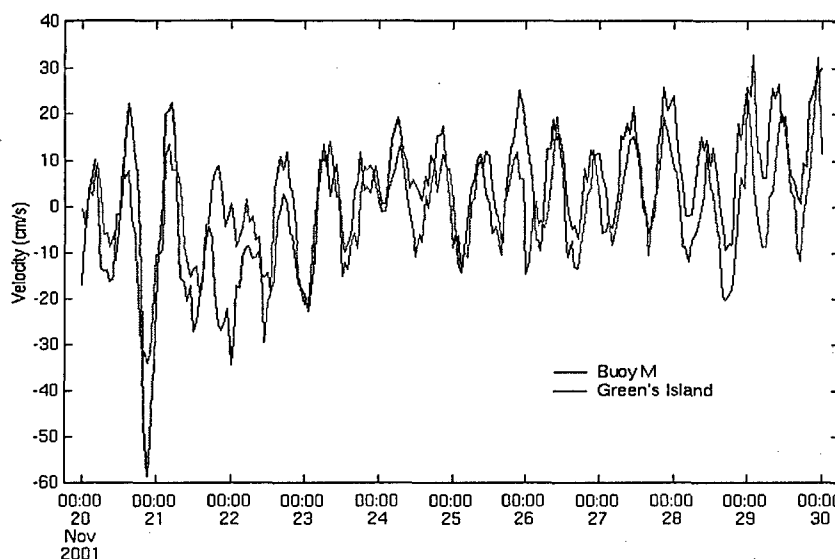
HF radars have been used for several decades to measure surface currents. Until recently their range was limited to roughly 50 km and there was little direct comparison with *in situ* current measurements to show that the technique actually worked. However, recent developments and testing made CODAR a natural research and development project for GoMOOS.

The new long range CODAR (radio frequency ~5 kHz, range ~200 km) was being tested during the conceptual-development period of the GoMOOS proposal. The range of CODAR's new long-range system was expected to be sufficiently long that four strategically placed units could cover the whole GOM. At the same time new test results from Professor Glenn at Rutgers University had shown an excellent correlation between high resolution CODAR and tidal currents measured by Acoustic Doppler Profilers.

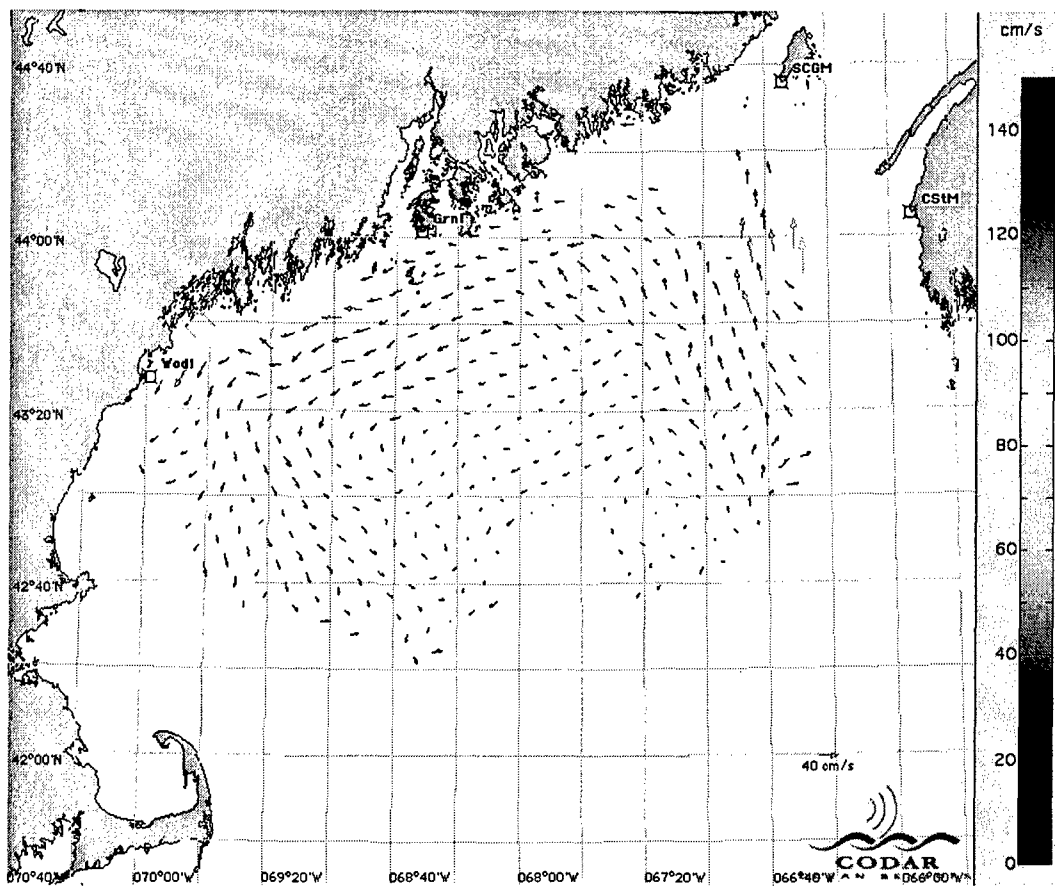
The first GoMOOS CODAR station was installed in the early fall of 2001 on Greens Island near the mouth of Penobscot Bay along the central GOM coast. Early tests of the

performance of this unit have been excellent. The range and azimuthal coverage from this location at times exceeded 200 km and 180°. However, it was discovered that nighttime ranges were curtailed by ionospheric radio interference. By trying different frequencies, this effect was reduced although not eliminated.

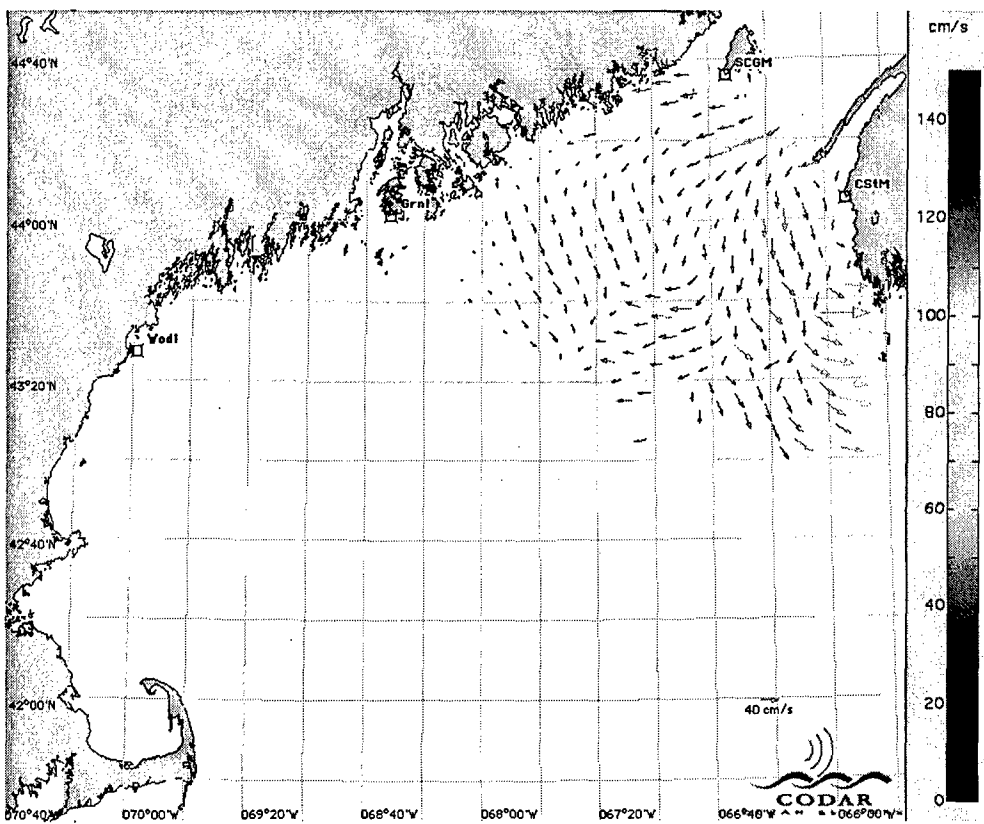
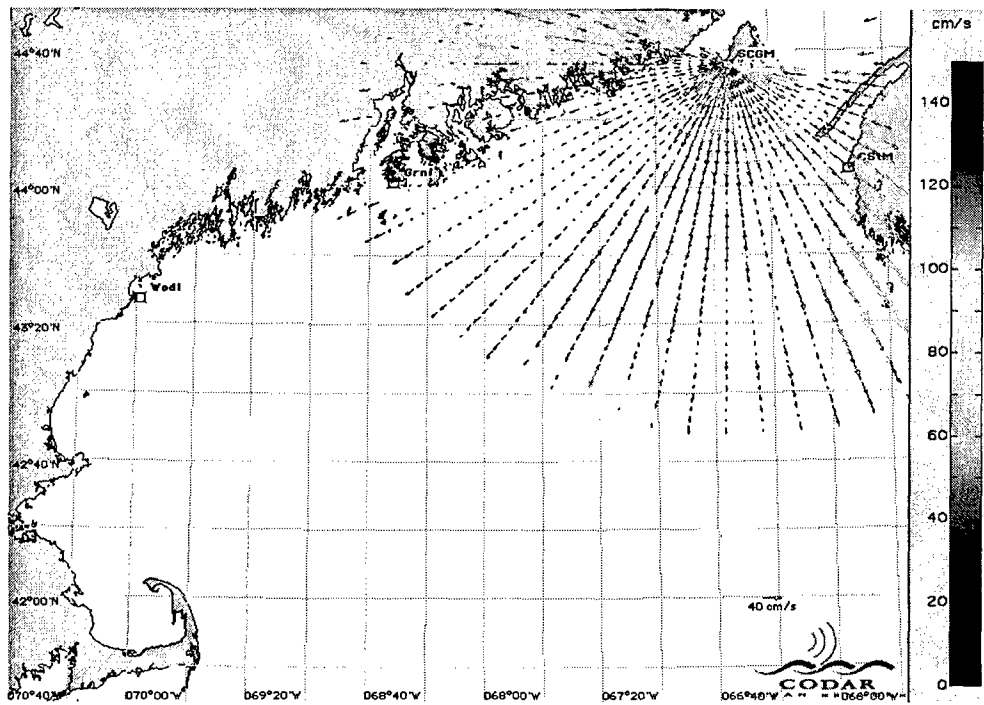
In order to obtain current vectors, two sets of overlapping radials are required. During the period when only the Greens Island site was installed in the GOM, we compared the radial component of the Buoy M surface current meter with the Greens Island CODAR radials. The comparison plot is shown below, confirming that the CODAR system provides meaningful measurements compared to state-of-art current meter data.



After the installation of additional CODAR units at Cape St. Mary, NS and at Wood Island Maine, we had the potential for full coverage in the eastern $\frac{3}{4}$ of the GOM. An example of the best coverage achieved by these installations is shown below. Unfortunately coverage this good is rare. It only occurs in daytime hours when ionospheric interference is at a minimum, and when the winds are vigorous so that there is a good wave field for Bragg scattering of the radar. Even under the best of conditions, there is an important gap in the data in both the eastern and western regions. The east, in particular, is a significant problem. This area is where the inflow from the Scotian Shelf and the Eastern Maine Coastal Current (EMCC) both occur.



To close the CODAR gap in eastern Maine, PhOG has tested a unit on Grand Manan Island in NB, Canada, and has applied for a license to operate. The results of the tests are shown below. The first plot shows the extent of the Grand Manan Radials, and the second shows the resultant vector coverage using only the two Canadian sites. The results are excellent and suggest that the addition of this site would make a major difference in the surface current coverage in this important region. The CODAR coverage has great potential utility for Search and Rescue operations of both the Canadian and American Coast Guards, oil spill trajectory predictions (this region is near Saint John NB which is the largest petroleum port in the Gulf of Maine, and one of the largest on the East Coast of North America), and potentially for long-range tracking of ships (homeland security).



Buoy and CODAR Program Progress Summary

GoMOOS demonstrated early success and continues to improve as GoMOOS transitions to operational status. Buoys have proven rugged enough to withstand the severe winter environment in the GOM, and their real-time data delivery has proven reliable. Overall the GoMOOS buoy system has been a reliable and versatile performer. We expect continued improvements when funding becomes available to include the deployment new data logger systems that will allow easy addition of multiple sensor packages from outside scientific groups. The "split brain" system would allow complete third-party remote control of sensors while protecting the operational system.

The new long-range CODAR system shows great promise for remotely sensing surface currents over the bulk of the GOM. The inclusion of a new site on Grand Manan Island, NB, Canada holds great promise for greatly improved temporal and spatial coverage.

BUOY ARRAY: Dr. Neal Pettigrew

Shelf Buoys:

- Atmospheric pressure porting system was redesigned and installed on the buoys.
- Two brands of Sonic Anemometers were lab tested and then added to the buoys for the first round of field testing on six of the GoMOOS buoys. It is hoped that these systems will reduce anemometer failure rates found with traditional spinning systems.
- New CDMA telemetry systems were developed, tested, and added to Buoys A, B, and C (replacing the analog cell phone system).
- The entire GoMOOS Buoy array was recovered and the buoys and sensors replaced during the fall turn-around period as planned (completed 10/22/05).
- All data was downloaded from the recovered sensors and the GoMOOS data archive was updated. Real-time data (which may have data gaps) were replaced with the full records.
- Work began to prepare the recovered buoy systems for redeployment in the spring of 2006. Buoy electronics and telemetry systems have been checked and repaired as needed.
- Sensors were cleaned and serviced and are ready for redeployment at this time.
- New automated QA/QC procedures were implemented in the data system.
- A system for calibration of A/D converters was developed and will be implemented before next deployment.
- A concrete compound anchor system was designed and deployed for Northeast Channel Buoy. The new anchor is expected to reduce or eliminate "storm walking" by the elastic-tethered mooring. The new anchor system will also result in substantial savings (~90%) compared with the steel cast system used previously.

- Added optics to Buoy A to support monitoring interests of the Massachusetts Water Resources Authority.

New Meadows Near-Shore Buoy

- GoMOOS will be deploying a near-shore buoy at the mouth of the New Meadows River (Brunswick/Phippsburg, Maine). The current meter data from these deployments will be the first long-term measurements of the unique circulation system in the New Meadows River. The addition of the meteorological sensors will also allow the evaluation of the role of local wind forcing (which is often modified by estuary shorelines) in the generation or modulation of the observed circulation patterns. The buoy has been designed and the mechanical drawings sent out to bid.
- Buoy electronics for the near-shore buoy were designed. One set of Buoy electronics has been fabricated for spring '06 deployment of the buoy.

CODAR ARRAY: Dr. Neal Pettigrew

The CODAR program relayed its first gulf-wide data on surface currents in June 2005. The quality of the coverage varies depending on the roughness of the sea (the rougher the conditions, the better the data), the time of day (night-time readings are lower) and radio disturbances. When conditions are right, the system can get excellent coverage of the Gulf of Maine. As further described in the bullets below, major new progress has been achieved on a significant enhancement of CODAR operations with the development of Artificial Neural Network ("ANN") models to fill data gaps and to enhance quality control of HF RADAR surface current data. A new, and much needed, site has been secured for trial operations on Grand Manan Island. Reliability of the existing CODAR sites in the Gulf of Maine has been improved, but communication problems remain.

- Preliminary permission has been obtained from the Canadian Coast Guard to deploy a CODAR unit for testing on Grand Manan Island. This diplomatic breakthrough will eliminate the major problem with the previous CODAR array which was excessive distance between coastal installations.
- Major progress has been made on the use of Artificial Neural Network modeling techniques to fill missing data in the CODAR data streams. Preliminary work using the ANNs to assist in QA/QC is also very promising.
- New computers were installed at two of the CODAR sites to improve system reliability and automatic recovery from power outages.
- Data communications at two island sites (Green's and Wood) have been problematic. Wireless service interruptions have been traced and remedied on Greens Island. Problems on Wood Island have not yet been remedied. Plans are underway to switch to CDMA cellular telemetry.

Real-time Optical Data

Collin Roesler, Bigelow Laboratory for Ocean Sciences

Contract Description

The contract to the Bigelow Laboratory for Ocean Sciences was for the design and development the optical sensing program for implementation of the initial phase of the Gulf of Maine Ocean Observing System (GoMOOS). Dr. Collin Roesler provided oversight of the optical program for GoMOOS. The work tasks included developing instrument packages for deployment on the moored buoy array, in concert with the guidelines provided by University of Maine (Pettigrew) and Woods Hole Oceanographic Institution (Irish), and data processing capacity to provide real-time optical data. The contract was for the design/deployment of: (1) two shelf buoys, heavily instrumented with surface multi-channel radiance and irradiance sensors, absorption and attenuation meters and backscattering sensors, and a series of paired chlorophyll fluorometers and irradiance sensors located within the euphotic zone; (2) two shelf buoys and a basin buoy instrumented with the series of paired chlorophyll fluorometers/irradiance sensors. The contract for data handling/delivery was (1) the development of computer software to handle routine processing of optical data; (2) to ensure the continuous and routine delivery in near real time to the Gulf of Maine Information Management System (GoMIMS); and (3) work with other principal investigators on the development of integrated data products from the optical data based upon the demands of the user group.

Accomplishments and Status

All the activities presented in this report have been performed by Collin Roesler (project PI) and Andrew Barnard (project Post Doctoral Researcher, 2001-2003).

Instruments

A suite of instrumentation for the detection of bio-optical properties (Table 1) was purchased. These instruments, as proposed, provide estimates of spectral absorption, attenuation, backscattering functions, downward irradiance and upward radiance, and chlorophyll fluorescence. Because the Campbell data logger has limited capacity for data collection, on board data processing and data communication, it was necessary design, construct and configure a data handler (WET Labs DH4) that would provide instrument control, power control, rudimentary data processing, raw data logging, and output a single stream of data to the Campbell data logger on each mooring. We worked with WETLabs, Inc., on the design and specifications of the DH4. GoMOOS provided the alpha and beta testing environment for the instruments which are now off the shelf and commercially available to the community. These DH4s communicate directly via a cable with the Campbell near surface instrument packages and via an inductive modem (SeaBird, Inc.) for the deep-water packages. While these were not part of the initial proposal, they were necessary for integration into the existing University of Maine buoy design. These instruments were also designed to activate a failsafe mode in the case that the Campbell communications failed. In the event that no hourly sampling command was

received from the Campbell, the DH4 initiates its own sampling and data storage so that upon retrieval, the entire data set of high resolution time series are retrieved. This mode has been implemented and resulted in months of rescued data. While utilizing the DH4 was initially in response to limitations on the Campbell, and their implementation was far from problem-free, our experiences have demonstrated the utility in redundant sites for sensor control, data storage and onboard data archiving, lessons that will no doubt be replicated in the next generations of observing systems.

Biofouling

Chlorophyll fluorometers and backscattering sensors were purchased with integrated copper shutter systems. These anti-biofouling agents were demonstrated to work remarkably well, with minimal fouling impacts after 6 months of deployment. Irradiance and radiance sensors were initially deployed with minimal anti-biofouling precautions (copper foil around sensing heads). Some fouling was observed upon recovery. Working with Satlantic, Inc., a copper shutter system was designed and manufactured to mitigate fouling on the sensor heads. These shutters rotate out of the detection plane while instruments collect data, software had to be modified to ignore those observations taken while impacted by shutter. All packages are now equipped with shutters. The absorption and attenuation meters (WET Labs ac9) were equipped with 25 cm of copper tubing on both the intake and outflow ports of both the a and c sampling tubes. This tubing allows copper to dissolve and fill the sample volume in between samples. The instrument is programmed to flush this water out before the start of sampling. After 6-month deployments little evidence of biofouling is generally observed in the data or on the optical sensing surfaces. These anti-biofouling steps enabled us to deploy the optical packages for the full 6-month deployment without having to service them every three months as had been planned in the original proposal. The extreme success in our anti-biofouling program necessitated that we purchase double battery power for each package to power instruments for 6-month deployments.

One of the challenges with regards to biofouling is how to identify it in real time data streams. Our system is designed such that each data product is redundant. For example, we have three means for assessing phytoplankton biomass: chlorophyll fluorescence, the chlorophyll absorption peak at 676 nm, and the diffuse attenuation coefficient at 676 nm, each of which is determined not only with a different sensor but through unique computations. Thus, if all three signals demonstrate coherent temporal patterns, we can be confident that we are observing a natural phenomenon. However, if the patterns are incoherent it suggests an instrumental artifact. Since we know how biofouling will impact each observation, it is possible to identify in real time and confirm upon recovery. We have found that biofouling does occur during particular seasons of high productivity and even with the success of the copper shutter/copper tubing/copper foil approach, it is necessary to maintain a protocol for determining biofouling and its impacts on the optical data streams (see next section).

Calibration/Characterization

All instruments undergo a careful and complete calibration and/or characterization when they are received from the company (Roesler and Boss, in press). Calibration is performed with pure water and in some cases known standards (i.e. chlorophyll a). There are several levels of characterization that are necessary. All instruments are regularly serviced and calibrated by the factory prior to deployment. All calibrations and characterizations are repeated in the laboratory after they are returned from the factory. This allows us to determine any damage incurred by shipment, and to apply, in some cases, our more sophisticated level of calibration than is performed by the factory. Instruments that are deployed for extended periods may undergo drift and/or biofouling. It is important to separate the effects of these two in order to achieve the highest degree of confidence in the data and to apply the correct calibrations. Once instruments are recovered from deployment, they are "recalibrated" in clean water before any organic coatings can dry then they are cleaned and recalibrated again in clean water. The difference between the clean post-recovery and pre-deployment calibration is used to quantify the instrument drift. The difference between the clean and dirty post-recovery calibrations is used to quantify the impacts of biofouling. How to apply these corrections to the post-recovery archived data streams depends upon the pattern of real time observations. Drift and even biofouling can present a monotonous pattern with time or more of a step function depending upon the situation. We look to the pattern of real time observations to aid in determining how to apply the post-recovery corrections (Figure 1).

Data analysis from deployments pointed to a temperature dependence in the signals from the chlorophyll fluorometers and the light sensors. We developed a full temperature characterization scheme to quantify this dependence. It is now incorporated into the automated, real-time data processing software (Figure 2).

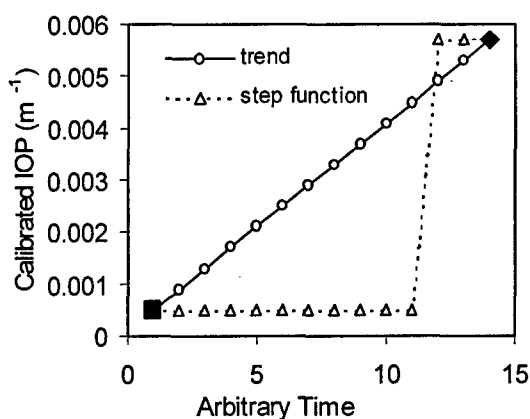


Figure 1. Hypothetical time course in pure water optical property observations (e.g. absorption, scattering or fluorescence) relative to pre-deployment factory calibration. An observed linear trend between pre- (filled square) and post- (filled diamond) deployment factory calibration is given by circles, a step function is given by triangles. These daily observations would indicate how to apply factory calibration to deployment observations during post-processing. From Roesler and Boss (in press).

These in situ observations and corrections were passed along to the respective manufacturers. It has resulted in some re-engineering of the sensors to minimize the thermal effects on the detectors. This again points to the fact that these types of real-time continuous observations are relatively unique to this program.

Package Descriptions

Instrument packages for each mooring are described in Table 1. Briefly, we designed three package types: the surface irradiance package, the underwater phytoplankton biomass/production package, and the underwater ocean color package.

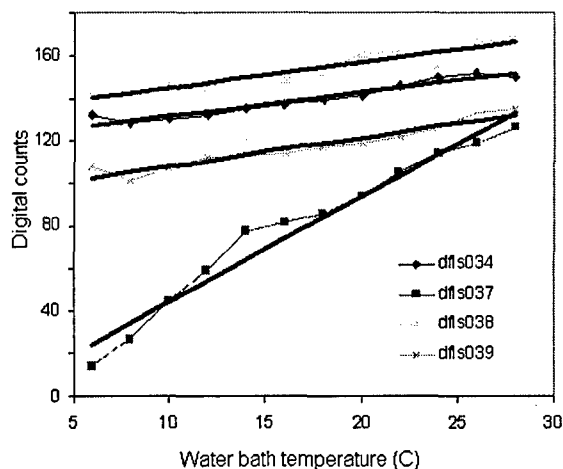


Figure 2. Example of the dependence of pure water counts on digital counts of the chlorophyll fluorometers (four different instruments). Sensors are typically calibrated at 25 C while in situ temperatures can be 5 C in the winter time. The difference of 30 to 100 digital counts in the baseline leads to underestimation of chlorophyll and in some cases negative values because the greatest errors occur at the lowest temperatures, conditions compounded by the fact that in situ chlorophyll, and hence digital fluorescence counts, are at their lowest values in the wintertime.

All optical moorings have the surface irradiance package, which consists of a 4- or 7-wavelength downward irradiance sensor and a data handler (DH4, which is configured within the well of the buoy). All optical moorings have the underwater phytoplankton biomass/production packages in the lower portion of the euphotic zone (approximately 18 - 30 m, depending upon location) and B, L, and M have had these packages deployed subsurface as well (~3m depth). These packages consist of paired chlorophyll fluorometers and 4-channel downward irradiance sensors. Moorings E and I have the ocean color packages deployed at the subsurface depth (~3m). The ocean color packages have a 7-channel upward radiance sensor, a nine-wavelength absorption-attenuation meter, and a three wavelength, three angle backscattering sensor in addition to the chlorophyll fluorometer and irradiance sensor. At these two sites the surface irradiance sensor is the 7-channel variety, where the 7 channels correspond to those of the ocean color satellite sensor SeaWiFS.

Deployment/Operational History

The record for operations history for the optics program has two aspects. The first is the real-time aspect for which the data have some gaps. The largest source of failure is in the Campbell-optics communication protocols and in cable damage. However, even in the case in which moorings were lost (either cables cut or buoys lost), once recovered, the data loggers demonstrate that hourly sampling was maintained for months afterwards (although data collected at the bottom of the GoM is not relevant to the program). This again points to the importance of data archiving redundancy (it is worth noting that in one or two cases, the on-board archiving protocol failed but the fact that the data are transmitted in real time resulted in no loss of data).

Data handling/delivery

All data from the optical packages are collected and logged on the DH4 cards. This data are retrieved and processed after recovery and these are the data that will be used to update the database and web pages. The post processing of archived data has been a bit problematic as we have waited until this summer to obtain software from WET Labs to access the archived files. We are in the process of complete reprocessing of the archived data for final QA/QC and processing to data products. Once complete, this data can be made available to the GoMOOS web team for dissemination on the web site. Currently on the historical real time data is available, which does not reflect the true status of the optical data streams (either in completeness or in quality).

The real time hourly observations are reduced to means by the DH4 firmware and communicated to the Campbell system either directly or via inductive modem for transmission over the cell phone. Initially data were extracted from the data stream at University of Maine and delivered hourly via ftp (Python script) to our computer at Bigelow. The data are processed to geophysical units (calibrations applied) and products are computed (using developed algorithms) using Matlab scripts. These scripts include quality control and assurance subroutines on all instrumentation. Both raw and processed data and data products are archived and are written to daily files for each mooring. These files are updated hourly, and are made available to the GoMOOS information system under a public http area. In late 2002, it was suggested that all processing be moved to the University of Maine. All processing scripts were supplied in Matlab and were subsequently rewritten in netcdf, unfortunately losing the module architecture. Since that time the key personnel responsible for this have moved on, leaving a legacy that has resulted in less than acceptable data products and problematic processing for the UMO group. We are in the process of rewriting all processing scripts as they were originally in Matlab modules for ease of processing at UMO. This will result in far superior real time data streams and data products.

Data Products

We originally proposed to produce the following data products: chlorophyll concentration, spectral downwelling irradiance, spectral upwelling radiance, spectral diffuse attenuation, downwelling irradiance of PAR, spectral absorption, scattering, backscattering, and beam attenuation coefficients. In addition to these we are producing: clear sky atmosphere spectral downwelling irradiance, clear sky atmosphere downwelling irradiance of PAR, percent cloud cover, cloud conditions, depth of percent light level, gross integrated primary production, underwater visibility, water color, water turbidity, remote sensing reflectance, community structure, and a blooms index. We had worked with staff at the GoMOOS office to develop informational web pages for the higher level, more complex optical products. However, a decision was made not to implement these pages and not to display the higher order optical data beyond Chl and incident irradiance on the official web site. However, we maintain routine processing of the data products (see section on results for examples).

Difference Between Current and Proposed Program

While we had planned to deploy optical packages on five moorings, and we have had instruments deployed on B, E, I, L, and M, the loss of L for 7 months made us reconsider that location for our small program. In the meantime we had to put funds for (1) the development and purchase of DH4 units for all packages, (2) additional batteries (for 6 month deployments) for all packages, (3) complete cable replacement for each deployment due to excessive wear during deployment, (4) shutters for irradiance sensors. These additional expenditures meant that we only had sufficient funds for 4 complete moorings. We have also found that the lack of redundancy makes for very difficult recovery/redeployment cruises. Thus the few pieces of instrumentation that were in reserve have been put towards the development of redundant instrument packages. After four years we have nearly complete redundancy. However, we are now entering the period in which instrument lifetimes will begin to result in the necessity for replacement. A plan will have to be made to prioritize this replacement to those essential instruments during funding cutbacks.

Transition to an Operational Observing System

We are working towards the goal of making the purchase, calibration, and deployment/recovery of our optical program operational and transferable to any observing system. The steps that we have taken towards this goal are as follows:

System Design

All of our instrument packages are stand-alone. The modification of the original proposed packages to the current package includes the DH4 data handler, which allows for independent control on all instrumentation, instrument power, in situ data processing and data transmission via rs232 protocols. These systems can be placed on any mooring and can provide data streams in any required format. Additionally they provide the capability for being removed from real time mode, relocated on the mooring chain and deployed in self-logging mode if necessary.

Instrument Design

All of our instrument packages are off the shelf. There is no additional engineering required for them to be operational.

Instrument Calibration and Characterization

All instruments come from the factory calibrated. Given 100% redundancy, it would be possible to return instruments to factory for calibration between deployments. However, it is very important for instruments to be post calibrated right out of the water to properly characterize biofouling. Additionally, they need to be cleaned and calibrated again to quantify instrument drift. This needs to be performed during the deployment/recovery cruises by a trained technician with oversight by a trained professional (i.e. PI or

equivalent). Factory supplied instruments are not characterized. These characterizations are necessary to discern real signals from artifacts and must be performed by a trained professional. Some of the steps could become routine for a trained technician with oversight by a trained professional.

Data Quality Control and Assurance

All data are put through qc/qa at the processing level based upon a standardized criteria. However, there are a number of instances in which it is necessary to validate signals using ancillary data. We have developed schemes for such validation but it is likely that this type of assurance may never be operational.

Data Interpretation

As with data QC/QA, this will not be an operational mode for observing systems, as it requires a trained professional scientist.

Examples of Results

I. Seasonal Phytoplankton Blooms in the Gulf of Maine

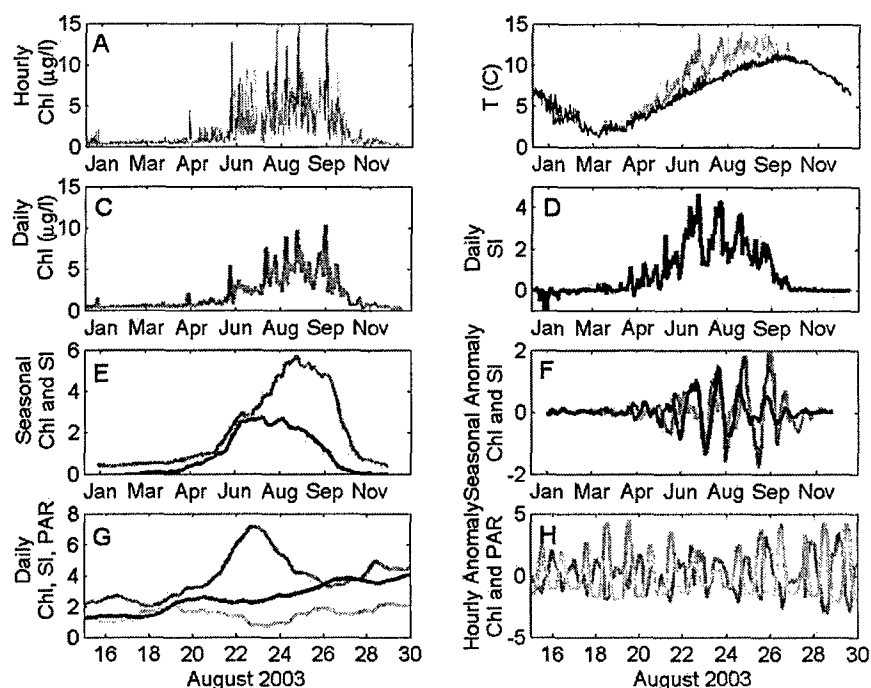


Figure 2. Physical controls on phytoplankton biomass at Mooring I in the Gulf of Maine.

A. Hourly observations of chlorophyll fluorescence (note these are 3 deployments).

B. Hourly observations of temperature at 0m (cyan), 20 m (blue) and 50 m (black).

C. Daily chlorophyll concentration determined from night time observations in which photochemical quenching of fluorescence was removed. This step is important because fluorescence is sensitive not only to chlorophyll concentration but to the phytoplankton physiological response to light (see H).

D. Daily observations of the stratification index (the difference between the 0m and 20m temperature observations), indicates how stable the water column is.

E. The seasonal pattern in phytoplankton biomass and stratification determined from low-pass filter of C and D, respectively. The patterns are significantly correlated ($r > 0.97$) with the peak in phytoplankton biomass lagging the peak in stratification by ~27 days.

F. The daily anomalies in phytoplankton biomass and stratification (the seasonal cycle removed from the daily observations) are also significantly correlated ($r > 0.42$) with each stratification/destratification event is coupled with a phytoplankton bloom event with a lag of ~30 hours indicating the phytoplankton rapidly respond to mixing and the input of new nutrients from deep waters. The lower correlation is likely due to the fact that the amplitude of the anomalies are not correlated although the timing is. The amplitudes are driven by the magnitude of the seasonal biomass.

G. Two week time series of daily chlorophyll, stratification and photosynthetically available radiation (PAR) in August 2003 during one of the mini bloom events.

H. The hourly anomalies in chlorophyll fluorescence and PAR, form the same time period as in G, are significantly inversely correlated ($r > -0.62$) with no lag, such that fluorescence is minimal when PAR is maximal and further that it is responsive to natural variations in PAR induced by clouds. This demonstrates that the in situ hourly fluorescence signal is impacted by the phytoplankton physiological response to photochemical quenching, a phenomenon that impacts not just fluorescence but also photosyntheses. This latter source of variability, while problematic for computing hourly biomass estimates (hence the use of daily values for biomass), does provide physiological information which can be used to constrain photosynthetic models.

II. Geographic Variations in Seasonal Phytoplankton Blooms

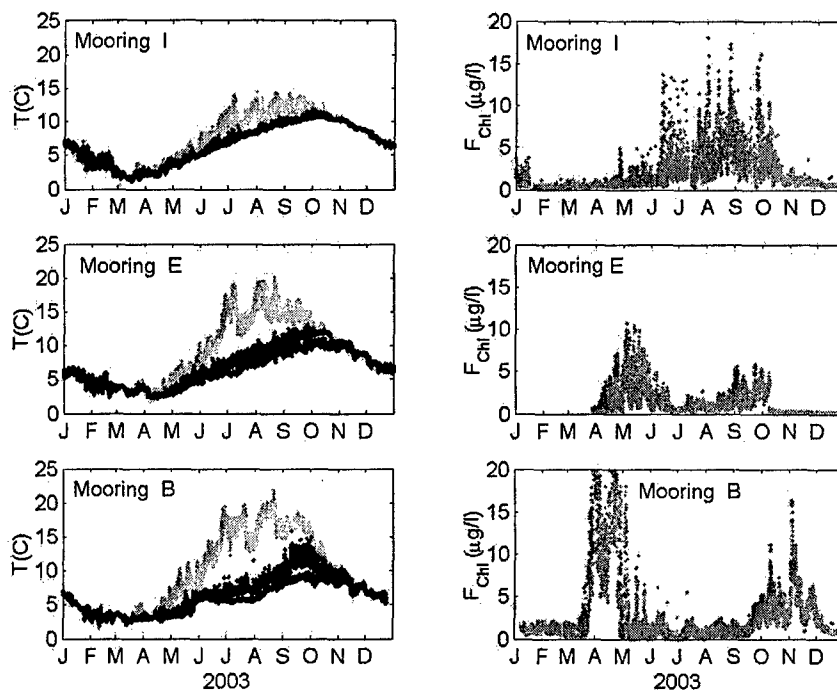


Figure 3. Hourly observations of temperature (left panel) and phytoplankton biomass (right panel) for moorings B, E, I (from bottom to top) located along the Gulf of Maine shelf from southwest to northeast, respectively.

The onset of spring time stratification begins in the southwest portion of the Gulf (Mooring B) and propagates NE along the shelf to mooring I, while the intensity of the stratification decreases from SW to NE. Given the response of phytoplankton to stratification it is expected that spring blooms initiate in the SW first and later in the NE, a pattern which is observed in the phytoplankton biomass. When the stratification intensity is high and the duration of stratification is long, nutrients in the surface waters are used up by the phytoplankton, zooplankton eat the phytoplankton and biomass exhibits a mid-summer minimum. The length of this minimum is a function of the length of the stratification season and its intensity. Because the NE surface waters are cooler, and stratification is weaker, than those in the SW, the autumnal cooling, which is nearly synoptic over the Gulf results in autumnal mixing that propagates from NE to SW, and autumnal phytoplankton blooms result from the pulses of new nutrients into the euphotic zone. Unlike the spring blooms, the pattern of these autumn blooms propagate from NE to SW. Thus the duration of the low biomass summer interval between the spring and autumn blooms decreases from SW to NE, and is absent at mooring I, with the spring and autumnal blooms essentially merging into one long bloom.

III. Interannual Variations in Phytoplankton Dynamics

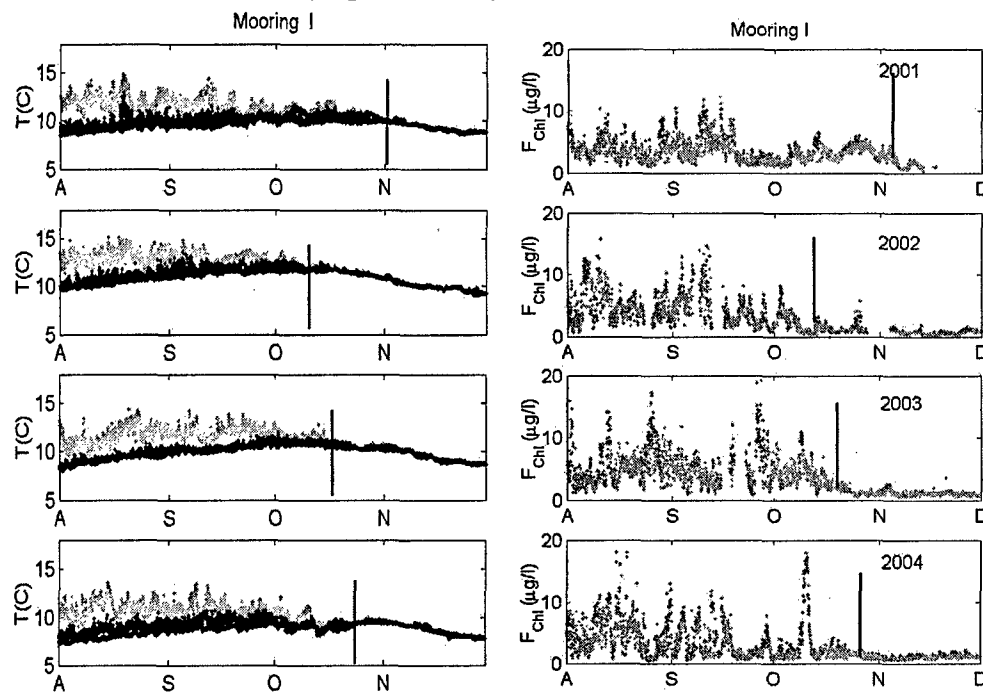
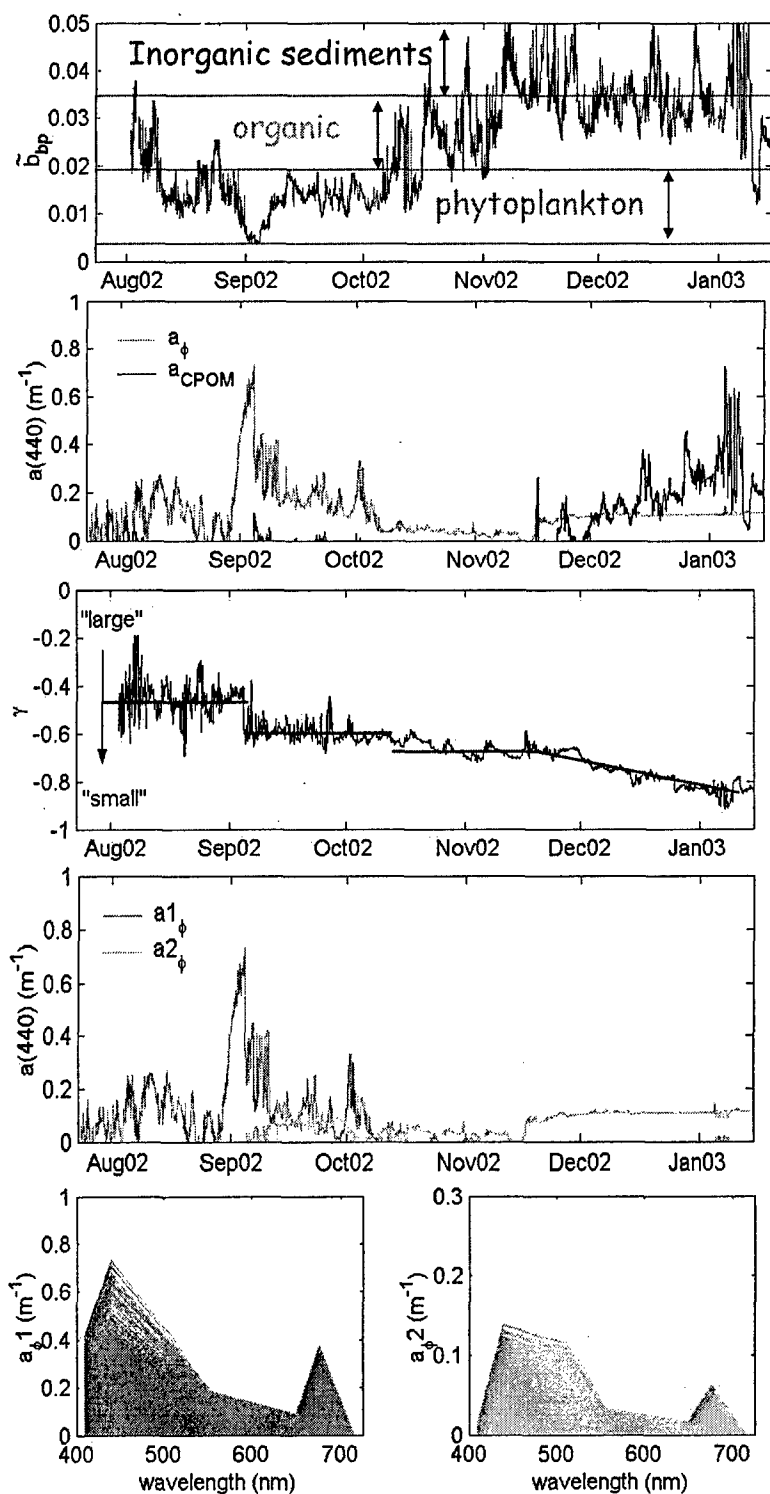


Figure 4. Interannual variability in the autumnal destratification as shown by the water temperature at 1m, 20m, and 50m (left panels, cyan, blue and black lines, respectively) and the phytoplankton biomass as indicated by the chlorophyll fluorescence (right panel) at mooring I for the years 2001 through 2004. Vertical blue lines indicate timing of final deep winter mixing.

The number of autumnal mixing events and the timing of the final overturn drives the autumn dynamics of phytoplankton biomass. The restratification event in October 2001 yielded a month-long bloom in comparison with 2002-2004, extending high biomass values into November. Given the pattern of the biomass, i.e. approximately gaussian with time, suggests that the biomass was grazed rather than lost to mixing or sinking. Whether or not there are zooplankton present which can exploit the phytoplankton biomass in this late season bloom is a question that cannot currently be answered with the existing observational system, but is of utmost importance with respect to trophodynamics and fisheries in the Gulf.

IV. Seasonal Patterns in Ecosystem Composition Using Higher Order Optical Products



cellular pigment concentrations, respectively, which is consistent with the mixing environment in which they dominate. By expanding optical sensing into the more complex observations, considerably more information about the seawater composition, particularly the particles, is possible.

Figure 5. Hourly patterns in optical proxies for ecosystem composition observed for the interval August 2002 through January 2003 at Mooring I. Particle composition is assessed via the A. backscattering ratio and B. absorption decomposition (modeled via Roesler et al. 1989). The particle composition in early August is dominated by non-algal organic particles, followed by dominance by phytoplankton from early August through October and transitioning to inorganic particles from November through January. One particular strength with the optical proxy approach is the redundancy in particle signatures obtained with different instrumentation. Confidence in the patterns is obtained when both proxies provide the same pattern as is demonstrated here. The particle size distribution is determined from the spectral slope of the beam attenuation coefficient (Boss et al. 2001). The early phytoplankton bloom is dominated by larger cells, while the later bloom in September is dominated by smaller cells. Finally the inorganic particles of the late season are even smaller in size, consistent with resuspension of benthic sediments in response to winter storm mixing (wind data not shown, but consistent).

Two phytoplankton populations (D) are observed in the total phytoplankton absorption times series from B, one dominant early in the time series as stratification begins to break down (green) and one later in the season dominant during destratified conditions (cyan). The absorption spectra for these components, determined from a modified version of the Roesler et al. 1989 model, are shown in the bottom panels (E and F).

and have very distinct spectral features consistent with populations adapted to high light, with strong absorption peaks, and low light, with flattened absorption peaks due to enhanced

V. Relationship Between In Situ Chlorophyll Concentration and Ocean Color Estimations

Ocean color reflectance is defined as the ratio of the upwelling light field that leaves the ocean surface to the downwelling incident light field (Figure 6). The upwelling light field originates from the incident solar irradiance that penetrates the upper ocean, is differentially absorbed and scattered by seawater and its particulate and dissolved constituents, and ultimately scattered back out the sea surface. Thus this upwelling light

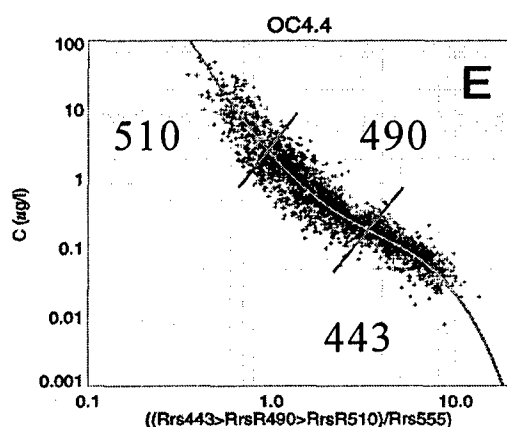


Figure 7. The basis for the NASA OC4.4 ocean color algorithm to estimate chlorophyll concentration from ocean color channel ratios. The chlorophyll concentration determines which channel is ratioed to the 555 nm channel, as indicated.

field contains the features of absorption and scattering by the upper ocean. The color of clear ocean water is blue because the only optically important constituent is water itself, which primarily absorbs red light and scatters blue light. Thus the only light that exits the ocean contains this signal is blue. As the concentration of phytoplankton and other constituents increases the absorption of blue light increases and the color of the ocean shifts from blue to green (Figure 6).

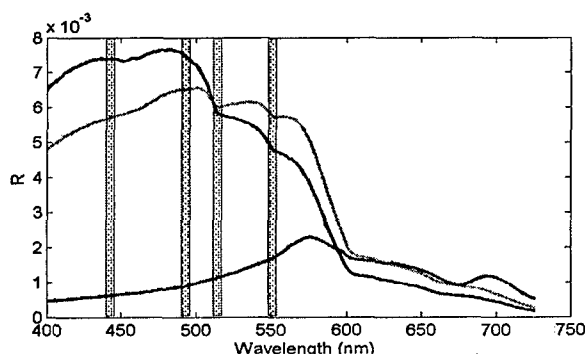


Figure 6. Examples of ocean color reflectance spectra from bright blue open ocean waters to green coastal waters to eutrophic bay waters (blue, green and red lines, respectively). The vertical bars indicate satellite-based ocean color sensors and those measured by the GoMOOS moorings E and I.

The retrieval of chlorophyll concentration from ocean color reflectance lies in the fact that phytoplankton, whose dominant pigment is chlorophyll, absorb blue light preferentially to green light (Figure 5 E and F). The algorithm employed by NASA is such that the ratio of ocean color measured at each of these wavelengths (essentially the blue to green light slope) is related to chlorophyll concentration.

When we compare the ocean color estimated chlorophyll concentration that we calculate from the radiometers on the GoMOOS moorings with that estimated from the chlorophyll fluorometers we find a general good agreement (Figure 8) with respect to the time series pattern. However, upon closure examination we find that there are certain times of year for which the chlorophyll concentration is quite overestimated and that occurs in the

winter time when chlorophyll is generally low due to low plant biomass but colored dissolved organic matter from rivers is very high. This CDOM has a very strong absorption coefficient in the blue and thus impacts the ocean color reflectance signature in a very similar way that chlorophyll does. By measuring other optical properties that provide estimates of CDOM we can better refine the ocean color approach.

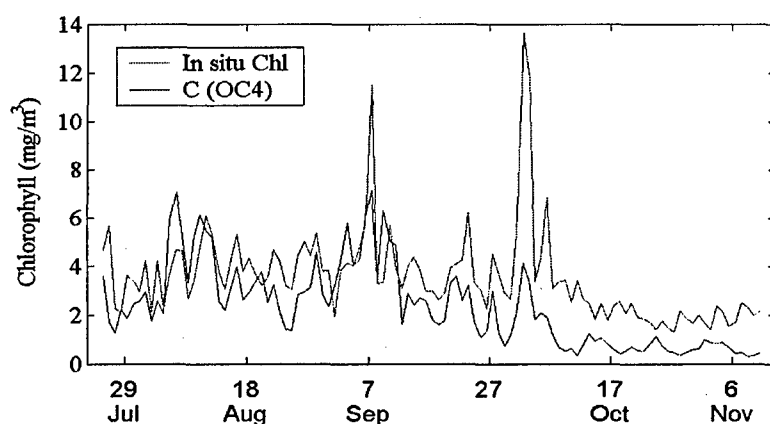


Figure 8. Time series of in situ chlorophyll concentration estimated from fluorometers (blue) and from ocean color algorithms applied to radiometric observations (green) on buoy I.

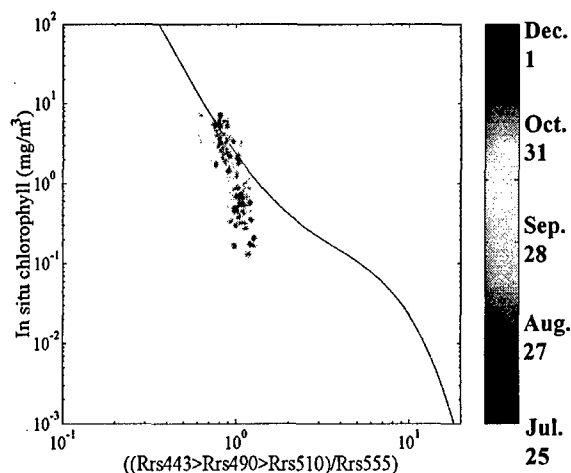


Figure 9. In situ chlorophyll concentrations estimated from fluorometers versus the ocean color ratios with the NASA algorithm relationship from Figure 7 shown. The winter is when the algorithm fails. Absorption observations from this same time period confirm the presence of high CDOM concentrations.

Table 1. Model, description, manufacturer and product derived all or in part by the observation, of bio-optical instruments deployed on the GoMOOS moorings. STD and OC refer to package type, STD is the standard paired chlorophyll fluorometer and light sensors, OC is the ocean color package which has additionally, ac9, vsf, Lu on the subsurface package and a 7 wavelength irradiance sensor instead of the 4 wavelength on the surface package. Surface packages sit on the buoy, subsurface packages at ~3m and deep packages between 18 and 30 m depending upon mooring site.

| Model | Description | Manufacturer | Derived Products | Package Depth, Package Type |
|------------|---|--------------|--|-----------------------------|
| OC504CSA | 4 wavelength irradiance sensor, in air | Satlantic | incident irradiance, %of clear sky radiation, radiance reflect | surface, STD |
| OC504CSW | 4 wavelength irradiance sensor, in water | Satlantic | PAR, spectral diffuse attenuation coefficient, light penetration depth, primary production | subsurface, all deep, all |
| OC507CSA | 7 wavelength irradiance sensor, in air | Satlantic | incident irradiance, %of clear sky radiation, radiance reflectance | surface, OC |
| OC507R10W | 7 wavelength radiance sensor, in water | Satlantic | spectral water leaving radiance, radiance reflectance, satellite-derived products | subsurface, OC |
| ac9 | 9 wavelength absorption and attenuation meter | WETLabs | spectral absorption and attenuation coefficients, turbidity (beam attenuation), constituent composition (phytoplankton biomass, non-algal particles, dissolved matter) and concentration, particle size distribution | subsurface, OC |
| VSF3 | 3 angle, 3 wavelength backscattering meter | WETLabs | spectral backscattering coefficients, backward volume scattering function, ocean color validation, bulk particle concentration and composition | subsurface, OC |
| DFLS | chlorophyll fluorometer | WETLabs | chlorophyll concentration, phytoplankton biomass, phytoplankton production | subsurface, all deep, all |
| DH4, DH4NC | data handler | WETLabs | controls, powers and integrates instrumentation, logs raw data, computes statistics, transfers means to Campbell data system. | subsurface, all deep, all |
| DH4NC | no-can data handler | WETLabs | NC refers to No-Can configuration, which sits directly in the buoy well and controls surface irradiance sensors. | surface, all |

Satellite Oceanography

Andrew Thomas, University of Maine

Overview

Satellite data, in conjunction with CODAR, are a principal means of obtaining operational synoptic coverage of ocean bio-geophysical parameters of the GOM region, placing *in situ* time series measurements into spatial context. In addition, historical archives and ongoing time series of satellite data provide a temporal context for both real-time satellite data retrievals and any *in situ* data available over short timeframes. The satellite data make possible comparisons of real time observations to a climatological database.

Satellite data received and processed at the University of Maine's Satellite Oceanography Data Laboratory (SODL) was one of the first geophysical products delivered to, and made available by, GoMOOS. The SODL maintains a research web site at WAVY.UMEOCE.MAINE.EDU. All activities and personnel are overseen by Andrew Thomas.

Wind Vectors (NASA's QuikSCAT Scatterometer)

Research quality wind retrievals (Level 3 binned data) for global fields are made available approximately 2-4 days after-the-fact via an ftp site at NASA's Jet Propulsion Laboratory (JPL). We established a direct relationship with the JPL laboratory and have developed automated scripts that retrieve these data into the SODL computer network as they are made available. Automated C-Shell scripts subset and re-map the fields to the Gulf of Maine region. Two parallel information/data products were developed: a) an annotated color coded JPEG for posting to the GoMOOS web site and archiving and b) a Hierarchical Data Format (HDF) data product for archiving. The later is available to interested users and to the database, when it becomes operational.

A summary of specific tasks and protocols developed for GoMOOS for the QuikSCAT data stream are given below:

- L3 binned data
- Acquisition of data from JPL PODAAC
- FTP data via C-shell scripts coordinated by cron jobs (data are HDF format)
- Processing and subsetting
- Develop and modify IDL scripts to ingest, subset, QC, and export data in GOMOOS compliant data format (HDF format). Execution is coordinated by cron jobs and C-shell scripts
- Export to GOMOOS data base
- Develop scripts in JAVA to import metadata and data to MySQL database (micmac.umeoce.maine.edu) Execution is coordinated by cron and c-shell script. Imagery was exported to original GOMOOS web page and is exported to SODL web page
- Near Real-Time quick-look data

- Acquisition of data from JPL PODAAC
- FTP from the near Real-Time Server (in VAP RMGDR format). Timing of data acquisition is optimized based on probability of data availability (we conducted tests with technical staff at JPL). FTP data via C-shell scripts executed by time-coordinated cron jobs (data are HDF format)
- Processing and subsetting Develop and modify IDL scripts to ingest, subset, QC, and export data in GOMOOS compliant data format (HDF format). Execution is coordinated by cron jobs and C-shell scripts.
- Export to GOMOOS data base
- Develop scripts in JAVA to import metadata and data to MySQL database (micmac.umeoce.maine.edu) Execution is coordinated by cron and C-shell script Export of imagery to the original GOMOOS web site. Created a "most-recent" image file for original GOMOOS website.

Surface Chlorophyll (SeaWiFS)

Scripts were developed that automatically download via ftp L1A SeaWiFS data covering the U.S. eastern seaboard from NASA Goddard Space Flight Center as they are made available in the NASA-defined research mode, which is approximately 2-3 weeks after-the-fact. Daily overpass data are subset to the Gulf of Maine region, processed to chlorophyll values using current NASA global coefficients and remapped to a standard projection matching that of the AVHRR SST data. Scripts were created that composite multiple daily scenes together into both 8-day and monthly composite products, thereby maximizing the ability of view features through clouds. Three products are created, 2 of which are posted onto the SODL web site: daily scenes (HDF files only, archived only), 8-day composites (jpeg available on-line at SODL web site, HDF file archived) and monthly composites (jpeg available on-line at SODL web site, HDF file archived). All products on the SODL website are posted behind statements warning of the proprietary nature of the data and stating that they are for "research use" only. All products are made available to GoMOOS.

A summary of specific tasks and protocols developed for GoMOOS for the SeaWiFS data stream are given below:

- Update processing coefficients and navigation parameters in SEADAS to conform to new NASA Reprocessing #3
- Complete reprocessing of entire SeaWiFS [chl] database for 1997-2000 (summer) into RP#3 to replace RP #2 data
- Customize data flagging thresholds in SEADAS processing to maximize data quality over the Gulf of Maine.
- Updated SeaDAS/IDL scripts to minimize user interaction – a single command script now controls the SeaDAS processing (1 month at a time), manages ancillary files, moves processed files to the SeaWiFS archive directories, creates JPEG images of GOM and subregion study areas, and updates the website – eliminates all user interaction except initiation

- Develop script to post “most recent” 8-day composite on original GoMOOS web site
- Continual modification of image annotation to make it user friendly
- Implement ftp download of LAC data from the DAAC automatically on a daily basis (C-shell script run by a cron job that reads the subscription e-mail, parses out the relevant ftp directory information and ftp’s the DAAC to download the data)

Sea Surface Temperatures (NOAA’s AVHRR)

These data are downloaded in real-time from the NOAA polar orbiting satellites by the SODL Seaspace Terascan © ground station on each overpass. Scripts have been written that automatically archive the raw swath data and pass Gulf of Maine sub scenes into a processing stream. This stream requires daily handling (except weekends) by trained personnel from the SODL to accurately navigate each scene, correcting for slight drift in computer clocks. After this, scripts were developed to process each orbit swath into two remapped, subset, cloud screened, sea surface temperature data products with 1.1km spatial resolution and 0.1°C thermal resolution, a) an annotated colorized jpeg which is posted to the SODL web page and archived and b) a digital data file for archiving. Annotation is added to these products including land masking, a vector coastline map, date, satellite number, and temperature scales in both F and C. Approximately 4-6 scenes are available each day, usually within 24 hours of overpass.

A summary of specific tasks and protocols developed for GoMOOS for the AVHRR SST data stream are given below:

- Terascan © system maintenance and administration, including:
 - a. Install new software (v 3.1)
 - b. Automate acquisition and export of GOM SST imagery to GOMOOS and SODL web page
 - c. Automate download of revised orbital elements files, automate update of GPS and system clock data
 - d. Test auto-navigation scripts
 - e. MCSST algorithm improvements (cloud masking)
 - f. Phase out of NOAA-15, phase in of NOAA-16 and NOAA-17 satellites
 - g. Trouble shoot and repair of tracking dish
 - h. On-site SeaSpace training in software upgrades and automated processing scripts
 - i. Consult with SeaSpace on improvement to software and customizing of certain functions
 - j. PERL scripting to automate and parse data products
 - k. Automated tape archiving and extraction

- Processing
 - a. Develop and improve IDL scripts to export data in GOMOOS compliant data format (HDF format). Execution is coordinated by cron jobs and C-shell scripts
 - b. Export to GOMOOS database
 - c. Develop scripts in JAVA to import metadata and data to MySQL database (micmac.umeoce.maine.edu) Execution is coordinated by cron and c-shell script
 - d. Imagery exported to original GOMOOS web page and to SODL web page

GoMOOS Progress Report: Satellite Data Systems

This project within GoMOOS handles the daily reception, processing, archiving, product generation and delivery of 4 different satellite data streams.

At this point, all systems are operating according to stated operational objectives / goals.

Operations include:

- 1) archive and deliver sea surface temperature maps derived from NOAA AVHRR sensor data. Four overpasses occur each day. These are processed / delivered the same day, requiring hands-on interaction from a trained operator for each image. In addition to the actual daily scenes, a number of higher-level statistical products are formed and sequentially updated, based on our 20 year climatology.
- 2) Archive and deliver NASA SeaWiFS chlorophyll images. Daily scenes are supplemented by higher level statistical products based on the 8 year climatology. In 2005, NASA has terminated the science license to 1km data. We are continuing to process and post the available 4km data, as these remain the most stable and accurate ocean color product available to the community.
- 3) Archive and deliver QuikSCAT wind vector images. Twice daily wind vector maps are created and delivered to GoMOOS. Quick-look products are presented same day. These are replaced by higher quality products 3-5 days afterwards, as the QCced and high quality data are made available from NASA.
- 4) Archive and deliver MODIS ocean color and sea surface temperature products. Data are acquired from NASA, processed and made available to GoMOOS. This system is being merged into one of direct data reception (see below).

Two major system operations are currently underway that involve partial GoMOOS funding.

a) Under separate funding, a new X-Band satellite reception system was acquired and installed in mid 2005 at Aubert Hall, allowing direct and real-time reception and processing of MODIS ocean color and sea surface temperature data. The system also allows direct reception of the Indian OCM satellite data stream, the annual license for which over an initial 3-year period was included in the NSF equipment grant that purchased the system. MODIS SST, MODIS chlorophyll and Indian OCM color

products are all planned for delivery to GoMOOS operations. System integration and calibration has been ongoing since the system was installed using separate funding. Significant effort was placed into diagnosing bugs and system components that were not performing correctly. The MODIS data stream now appears stable and consistent. GoMOOS aspects of this project are focused on product generation. Comparisons with similar NASA products are underway and preliminary GoMOOS products are now being delivered. The OCM data reception is consistent and stable, however, interpretation of the datastream is a continuing area of effort. The Indian sensor is not well calibrated and does not have an operational atmospheric correction scheme or calibration/validation program. At present, we are one of only 3 sites in the country dealing with this data, and our hope is that GoMOOS in-water instrumentation will provide a cal/val data stream against which to compare the data. This work is ongoing.

b) Using partial GoMOOS funding from last year, we have purchased an upgrade for the L-Band satellite reception facility (reception of AVHRR data). This was necessary, as the manufacturer will no longer provide support or software upgrades to our old (SOLARIS based) system after this year. The new reception system is in house and will be integrated into the system over the next few months. In addition to this new component integration, we will also have to re-locate the entire reception system from Libby Hall to Aubert Hall in early 2006. We anticipate all reception systems being down for a 2-3 day period during moving and new set up of the computer system.

Circulation Modeling

Huijie Xue, University of Maine

The GoMOOS circulation modeling focuses on applying operational numerical models to the Gulf of Maine region, making model results available via the web in real time in nowcast mode, and producing forecasts by coupling the circulation model with available meteorological forecasts. The great strengths of mathematical models from the observatory perspective are interpolation, extrapolation, integration, and prediction. This report summarizes the completed and the ongoing tasks of the modeling group at the University of Maine.

The Gulf of Maine nowcast/forecast system

The Gulf of Maine nowcast/forecast system (Xue et al., 2005) is based on the three-dimensional Princeton Ocean Model in a curvilinear grid (Figure 1). It is driven at the surface with heat, moisture, and momentum fluxes from the National Center for Environmental Prediction (NCEP)'s NAM mesoscale atmospheric forecast model. Boundary forcing includes daily river outflows from St. John, Penobscot, Kennebec, Androscoggin, Saco, and Merrimack, tidal (M_2 , S_2 , N_2 , K_1 , O_1 , and P_1) and subtidal forcing from the open ocean, which is interpolated from the daily nowcast of the NCEP Regional Ocean Forecast System (ROFS).

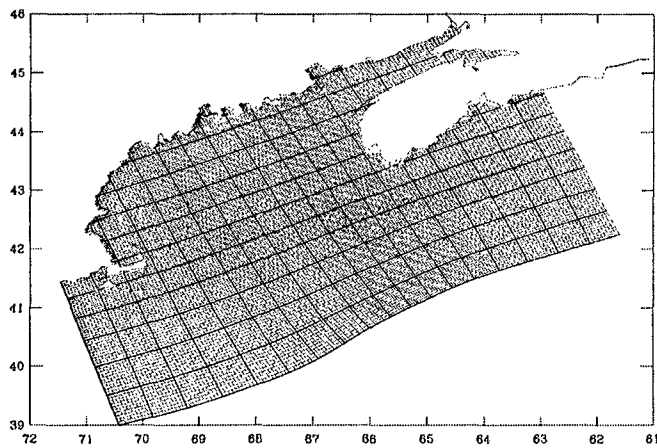


Figure 1. The Gulf of Maine circulation model grid.

The system has been operating in a quasi-operational mode since 2001. The automated daily procedure, which starts at 6:00 am everyday, includes three consecutive jobs: preprocessing, model integration, and post processing. Preprocessing downloads the necessary boundary condition and interpolates them to the Gulf of Maine grid. Model integration includes a nowcast cycle that assimilates the satellite SST and prepares the initial condition followed by a forecast cycle that predicts velocity, temperature, salinity, and sea level up to 48 hours. Post-processing includes data storage and update of the web interface (<http://rocky.umeoce.maine.edu/GoMPOM>). Temperature, salinity and velocity at three levels and surface elevation are shown graphically on the web at a 3-hour interval (Figure 2).

Skillful forecasts are made by using data to constrain the model in the assimilative manner. The Gulf of Maine nowcast/forecast system now includes assimilation of the satellite SST using an algorithm similar to that of Kelley et al. (1999). The algorithm described in details in Xue et al. (2005) consists of three elements: optimal interpolation;

mixed-layer adjustment; and successive correction. Since its implementation in July 2001, the SST assimilation scheme has produced robust SST patterns with realistic spatial and temporal variability. As well, seasonal variations of temperature in the upper 50m compare favorably with buoy observations (Xue et al., 2005).

We have developed a CODAR data assimilation scheme similar to that of Oke *et al.* (2002). Our first attempt was to assimilate the tidal residual current in the model. The scheme includes: a standard tidal analysis package to separate the tidal constituents both from the model output and from the CODAR velocity field, an incremental estimation of error covariance matrix and vertical cross-covariance vector based on the previous month's forecasts, an eigenvalue decomposition package to formulate an analyzed surface current field, and a statistical interpolation to project the analyzed surface current field vertically using the vertical cross-covariance vector. The three-dimension velocity correction field is then assimilated into the model by adding extra forcing to the pressure gradient term. The correction is introduced gradually, similar to the incremental analysis updating approach of Bloom *et al.* (1996). This scheme needs further tests.

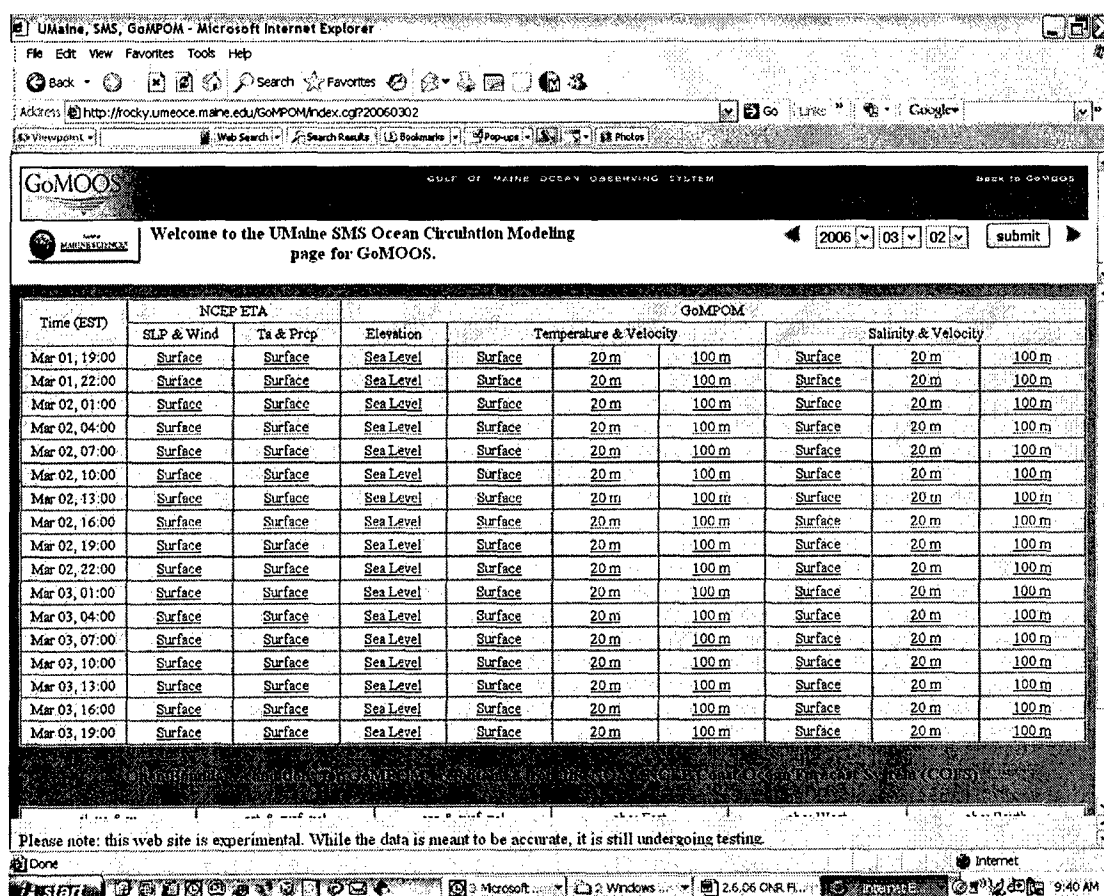


Figure 2. Daily web presentation of the Gulf of Maine circulation forecast.

Developed Products

Model Data Archive

There have been numerous minor updates to the nowcast/forecast system mostly associated with fine-tuning the SST assimilation algorithm, treatment of river discharges and tidal open boundary conditions. An operational log has been created to document the changes. The archive from 1 January 2002 to present, however, has been updated to reflect the most recent version of the nowcast/forecast system.

Archived daily are 3-hourly output from the nowcast/forecast system and more frequent output at certain locations and/or during certain periods of time requested by users. An example is that we provided Sharon Tsay of Metcalf and Eddy time series of model state variables of every 18 minutes for several locations on the shelf outside the Piscataqua Estuary. Restart files are archived for the first day of the month so hindcasts of specific events can be conducted at later times (for example, we are working with Michael Mickelson from Massachusetts Water Resource Authority to examine the responses of the Gulf of Maine to the Northeasters in May 2005).

We also calculated the mean, standard deviation, bias, and correlation coefficients between model predictions and buoy observations, which serves as a supplemental information for any one using the model output, especially in cases when uncertainty associated with the modeled fields is needed.

GUI Toolkits

In addition to the routine forecasts, we created monthly averages from the model predictions. The monthly averages are linked to a Live Access Server (LAS) (Figure 3). To accommodate curvilinear grid and η -coordinate in the LAS, we developed a wrapper that is available to all LAS users. The LAS interface allows to subset the model fields interactively through the web (<http://rocky.umeoce.maine.edu/las-GoMPOM/>), and it is also a useful tool in comparing model runs. Our goal is to include the LAS as a part of post-processing package so users will be able to sample the model predictions more freely.

Another toolkit that we developed is an interface that links the surface velocity fields generated by the GoMOOS nowcast/forecast system to the General NOAA Oilspill Modeling Environment (GNOME) (Figure 4). Instruction is available at <http://rocky.umeoce.maine.edu/GoMPOM/cdfs/GNOME/web/> for setting up this toolkit on personal computers. This can be used as a planning tool for NOAA emergency responders. It is also illustrative for the purpose of tracking water borne objects and organisms, especially those at the surface. In addition, it is an excellent teaching tool.

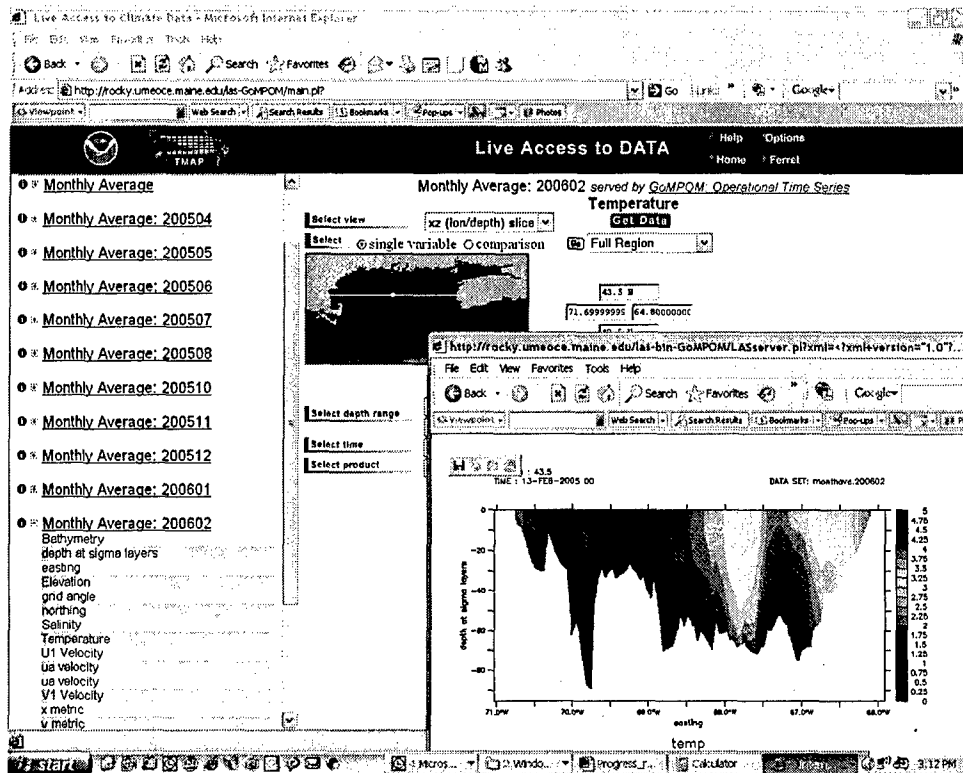


Figure 3. The LAS interface for the Gulf of Maine nowcast/forecast system.

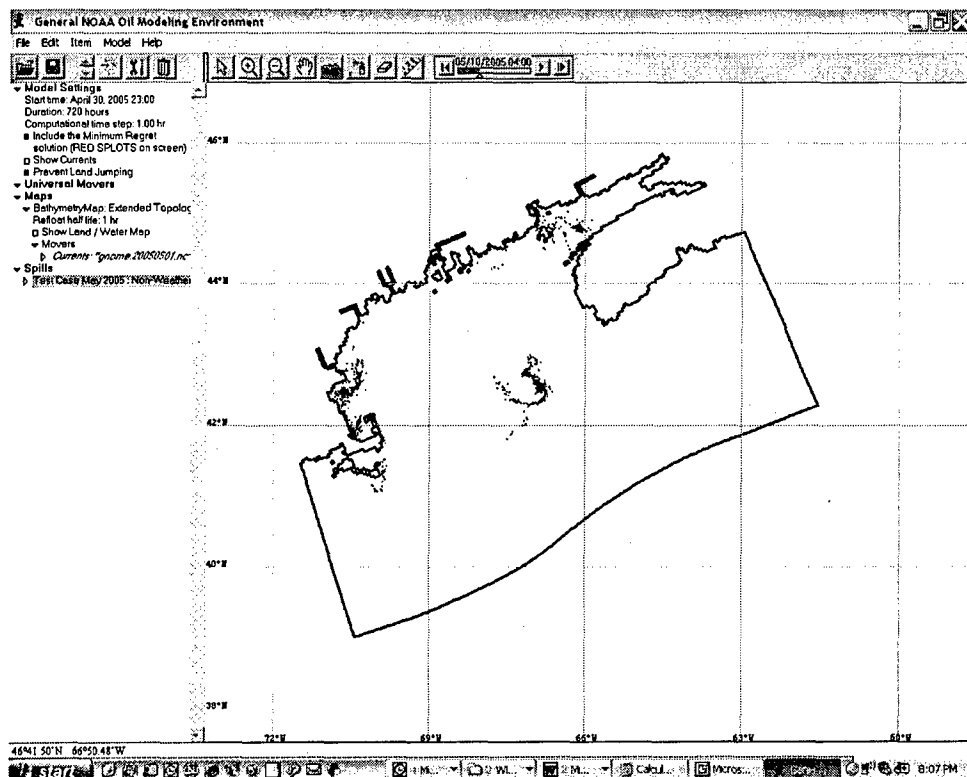


Figure 4. An example of the Gulf of Maine GNOME.

Publications

The following two peer-reviewed articles have been published.

- Xue. H., L. Shi, S. Cousins, and N. R. Pettigrew, 2005: The GoMOOS nowcast/forecast system. *Cont. Shelf Res.*, 25, 2122-2146.
- Xue. H., L. Shi, and S. Cousins, 2004: SST assimilation and assessment of the predicted temperature from the GoMOOS nowcast/forecast system. *Proceedings of the 8th International Conference on Coastal & Estuarine Modeling*, ASCE, 128-143.

In addition, the GoMOOS nowcast/forecast system was used in a synthesis study to examine the impact of transport processes on lobster fishery patterns in the Gulf of Maine. A paper is nearly ready for submission to *Ecological Modelling* by Xue, Incze, Xu, Wolff, and Pettigrew entitled "Circulation, Connectivity and transport of lobster larvae in the coastal Gulf of Maine".

Ongoing and Planned Tasks

We are collaborating with Dr. Charles Hannah (Bedford Institute of Oceanography, Department of Fisheries and Oceans, Canada) to incorporate climatological hydrographic data into the GoMOOS nowcast/forecast system. We began by examine systematically the error associated the boundary conditions derived from the NCEP ROFS when Dr. Hannah visited the University of Maine. We are also carrying out a sensitivity study on reducing the salinity bias in the boundary condition derived from the NCEP ROFS.

A high-resolution model (~ 1 km) is being tested. It has been integrated to the end of February 2004. It is not as robust as the operational version with trouble spots in Cape Cod Bay and St. Mary's Bay and near Grand Manan Island, especially if SST data assimilation is employed. We are investigating the effects of vertical adjustment in the assimilation algorithm, advection scheme, and resolution on water column stratification in sheltered shallow regions in the model. The progress is currently limited by CPU speed of the existing computational nodes in the lab. Stephen Cousins is working on a parallel version of the high-resolution model using the Scalable Modeling System (SMS) (Forecast Systems Laboratory, NOAA). We anticipate a dramatic speedup on development when the parallel code is ready on the University of Maine clusters.

A more urgent task, however, is to work with Drs. D. B. Rao and Carlos Lozano (NCEP/NOAA) to update the GoMOOS nowcast/forecast as NCEP is shifting from the POM based ROFS to a HYCOM based Real-Time Ocean Forecast System (RTOFS). RTOFS is a 1/12 deg Atlantic basin model with real-time atmospheric, tidal and river forcing. With the update, we need to conduct the hindcast of 2005 and perform skill assessment to establish the benchmark for the new system. The skill assessment will be expanded to include not only comparisons between GoMOOS nowcasts/forecasts and GoMOOS observations, but also comparisons of GoMOOS forecasts and observations with RTOFS forecasts with feedbacks to NCEP and climatology (in collaboration with Charles Hannah). Secondly, we plan to incorporate the updates into the high-resolution

model that we are developing. In addition, we plan to expand the forecast time to 72 hours.

References

- Bloom, S. C., L. L. Takacs, A. M. Da Silva, and D. Ledvina, 1996: Data assimilation using incremental analysis updates. *Mon. Wea. Rev.*, 124, 1256-1271.
- Kelley, J. G. W., D. W. Behringer, and H. J. Thiebaut, 1999: Description of the SST data assimilation system used in the NOAA coastal Ocean Forecast System (COFS) for the U.S. east coast. NOAA/NWS/NCEP, OMB Contribution No. 174. 49pp.
- Oke, P. R., J. S. Allen, R. N. Miller, G. D. Egbert, and P. M. Kosro, (2002): Assimilation of surface velocity data into a primitive equation coastal ocean model. *J. Geophys. Res.*, 107(C9), 3122, doi:10.1029/2000JC000511.
- Xue, H., L. Shi, S. Cousins, and N. R. Pettigrew, 2005: The GoMOOS nowcast/forecast system. *Cont. Shelf Res.*, 25, 2122-2146.

Surface Wave Forecasting in GoMOOS

Dr. Will Perrie, Bedford Institute of Oceanography

Accomplishments and Status

Wave Model

The operational NCEP model WaveWatch3 (hereafter, WW3) was implemented for a coarse-resolution grid of 1° for the entire N. Atlantic. The coarse-resolution WW3 was nested to an intermediate-resolution 0.2° WW3 implementation for the NW Atlantic. This domain is the same as the domain for the fine-resolution COAMPS winds from the US Navy FNMOC (Fleet Numerical Meteorological and Oceanographic Center). This domain is presently being extended to include the entire Gulf of Mexico region, as well as the Grand Banks of Newfoundland. The intermediate-resolution WW3 was nested to a fine-resolution 0.1° SWAN implementation for the Gulf of Maine and neighboring waters. Domains for coarse-, intermediate- and fine-resolution grid domains are given in Figures 1a-c, respectively.

The composite WW3-SWAN system was completed in Sept. 2002 and represents a significant technical accomplishment, because these two models have not been nested before. Thus, respective documentations for each model are unclear regarding actual nesting procedure and much of the work required careful examination of the codes to determine what each model was doing.

On-going issues relate to continuous error- checking throughout the model system, implementing patches and bug-fixes as reported by the model-user community, and implementing new model versions as they become available. We completed implementation of new releases of WaveWatch3 and SWAN during the last fiscal year 2005-06. These are versions ww3-v2.22 and swan-v40.31, respectively. These codes offer better utilization of computer resources in multi-CPU simulations, improved physics for wave propagation and in the wave source terms – which represent wind input and wave dissipation terms. But these new implementations were associated with many bugs, bug-fixes and patches, as reported by the wave modeling community, and also as we reported back to the wave modeling community.

Improvements in bottom topography, moving to more accurate bathymetry, as extensively optimized and tested at BIO and other laboratories, we have accessed higher resolution bathymetry for related areas of the northern Gulf of Maine. We still need to access more reliable bathymetry data for the central and southern portions of the Gulf, and Georges Bank, to provide a consistent coverage of the entire GoMOOS area.

Wave products are now available on an hourly basis, to allow users access to more timely products. As yet these products have not been posted on the website.

Winds

Winds were taken from the COAMPS model, for the fine- and intermediate-resolution domains (Figs. 1b-1c). For coarse-resolution grid points (Fig. 1a) outside the COAMPS region, NOGAPS wind data were used. Scripts were constructed to allow automatic

access to winds from the www.godae.org web-site. These winds have proven reliable and accurate for extratropical hurricanes such as Hurricane Juan, compared to other forecast office wind products. The system is now fully operational, with automatic downloads of winds from FNMOC, and wave forecasts posted on the website. Recently, we have started to use 3-hourly winds, to reduce biases in wind produces during fast moving storms. We hope to use hourly winds in the near future, perhaps from the Meteorological Service of Canada, or from FNMOC, if they are available. This would further reduce distortion in wind field products because 6-hourly winds have large intervals between wind field updates.

Wave Validation

Comparisons of wave forecasts with buoy measurements of wave heights are available online on the GoMOOS website, at selected GoMOOS buoys, for example the out buoys L, N and M indicated in Fig. 2. Online comparisons are not available with NDBC buoys 44005, 44011, or 44018, as yet. Clicking on the icon "Wave forecast plot" in http://www.gomoos.org/buoy/buoy_data.shtml brings up the comparisons, as shown in Figs. 3a-3c for high wave conditions of Feb. 17-18, 2006, verifying general model consistency with the measured data.

Case study: Hurricane Juan

Hurricane Juan made landfall at 12:10 a.m. ADT, Monday September 29, between Prospect and Peggy's Cove, Nova Scotia, and then moved northward across the central portion of the province, passing over Northumberland Strait and Prince Edward Island. This was a category 2 hurricane, associated with high waves in coastal waters, lashing shoreline villages and beaches from Peggy's Cove to Sheet Harbour. On Scotian Shelf, the height of these waves exceeded the 100-year return wave. This was the first major real-time test of the wave forecast system. Maximum winds exceeded 150 km/h, gusting to 176 km/h. Figures 4a-4c present COAMPS winds at 00 UTC on 29 September (9:00p.m. ADT on September 28), in comparison with blended scatterometer winds, using Florida State University satellite-wind algorithms, and Canadian Hurricane Centre (CHC) storm track analysis. The COAMPS storm track appears to be slightly to the east of that presented by scatterometer data and the CHC analysis.

The GoMOOS wave model system produced 48-hour wave forecasts, every 12 hours, before and during the passage of Juan. In the aftermath of the weeklong power blackout following Juan, the forecasts continued until 30 September, when BIO's back-up power was failing. As shown in Figs. 5a-5b, the wave model forecasts suggest significant wave heights (Hs) of almost 12 m for Scotian Shelf, at 00 UTC 29 September.

COAMPS winds were able to capture the timing of Juan's passage correctly, but did not completely simulate the peak storm intensity, or storm track. The actual storm track passed slightly to the west of the simulated COAMPS model forecast track over Scotian Shelf. Therefore, the COAMPS winds are too low at buoy 44258 at the mouth of Halifax Harbour (Fig. 6a), and at offshore buoy 44142 (Fig. 6b), and too high at offshore buoy 44137 (Fig. 6c), compared to measured winds. The largest Hs wave heights recorded at

buoy 44258 were almost 9 metres (Fig.7a), with maximum waves of about 20 metres. Corresponding wave model estimates from WW3 underestimated these waves by about 1 m, although the timing of the peak is very nearly correct. Maximum significant wave heights (Hs) of 12 m were measured at buoy 44142 on western Scotian Slope (Fig. 7b). Although the COAMPS winds and the WW3 wave forecast correctly simulated the timing of the storm, the observed Hs peak at this site was underestimated by about 4-5 m, and the observed winds were high by as much as ~15 m/s relative to COAMPS (Fig. 6b). Note however, that 12 m Hs waves were achieved within the WW3 wave field at 00 UTC (Fig. 5a). By comparison, a maximum observed Hs of 7 m, measured at buoy 44137 on eastern Scotian Slope (Fig.7c), was overestimated in the WW3 wave forecast by about 1 m, reflecting a systematic overestimate of the observed wind speed by about 1-2 m/s (Fig.6c). Again the forecast timing of the storm's passage was excellent at buoy 44137, so that in spite of slight quantitative errors related to storm track, the GoMOOS forecast for Hurricane Juan was essentially correct.

Figure 1(a) Coarse resolution (1.0°) domain for the operational WW3 forecasts.

Sig. Wave Heights (contours), Wave Directions (dir. of vectors), Wave Periods (length of vectors) At 2006021800



Fig. Wave Heights (contours), Wave Directions (dir. of vectors), Wave Periods (length of vectors) At 2006021800

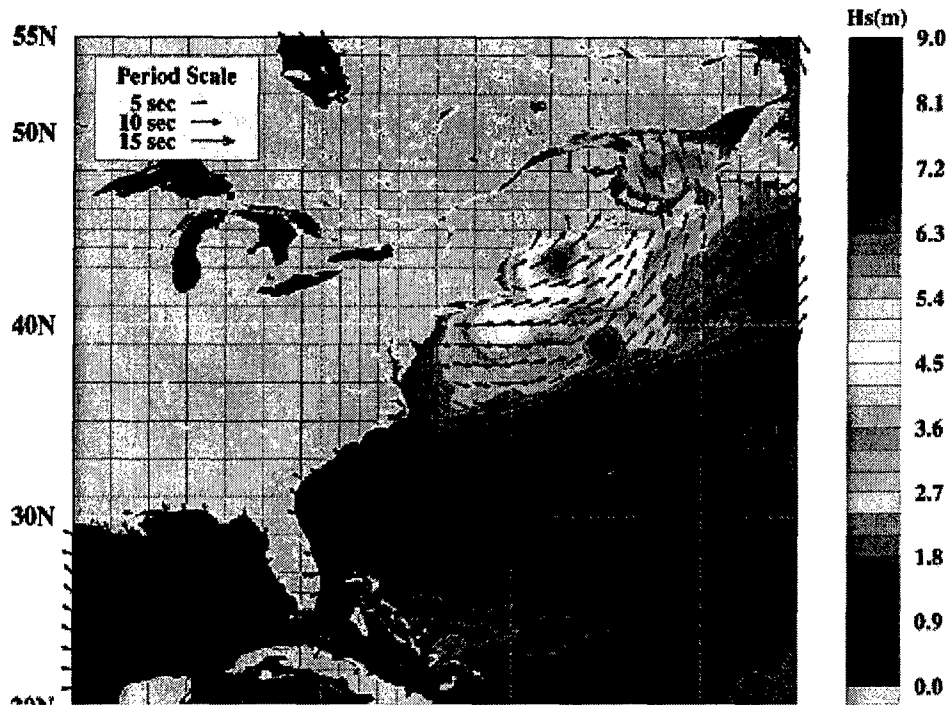


Figure 1(b) Intermediate resolution (0.2°) domain for the operational WW3 forecasts.

Fig. Wave Heights (contours), Wave Directions (dir. of vectors), Wave Periods (length of vectors) At 2006021800

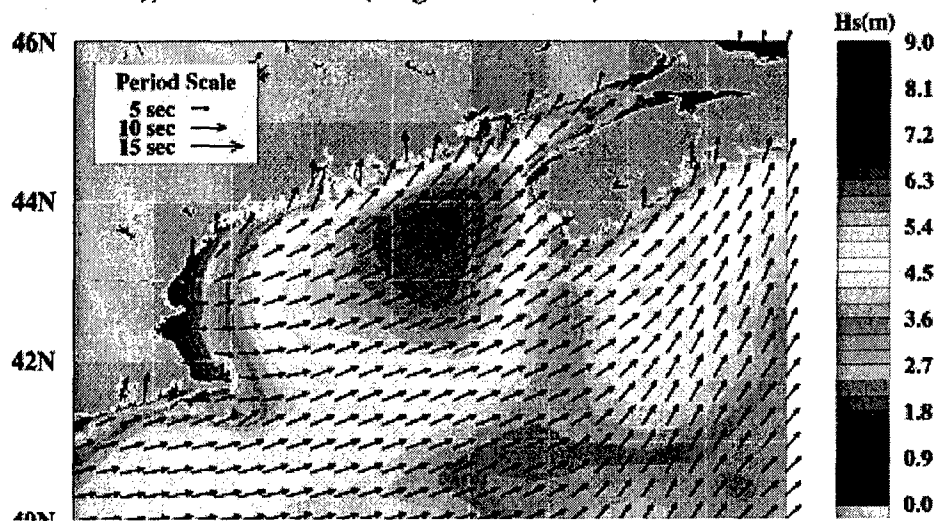
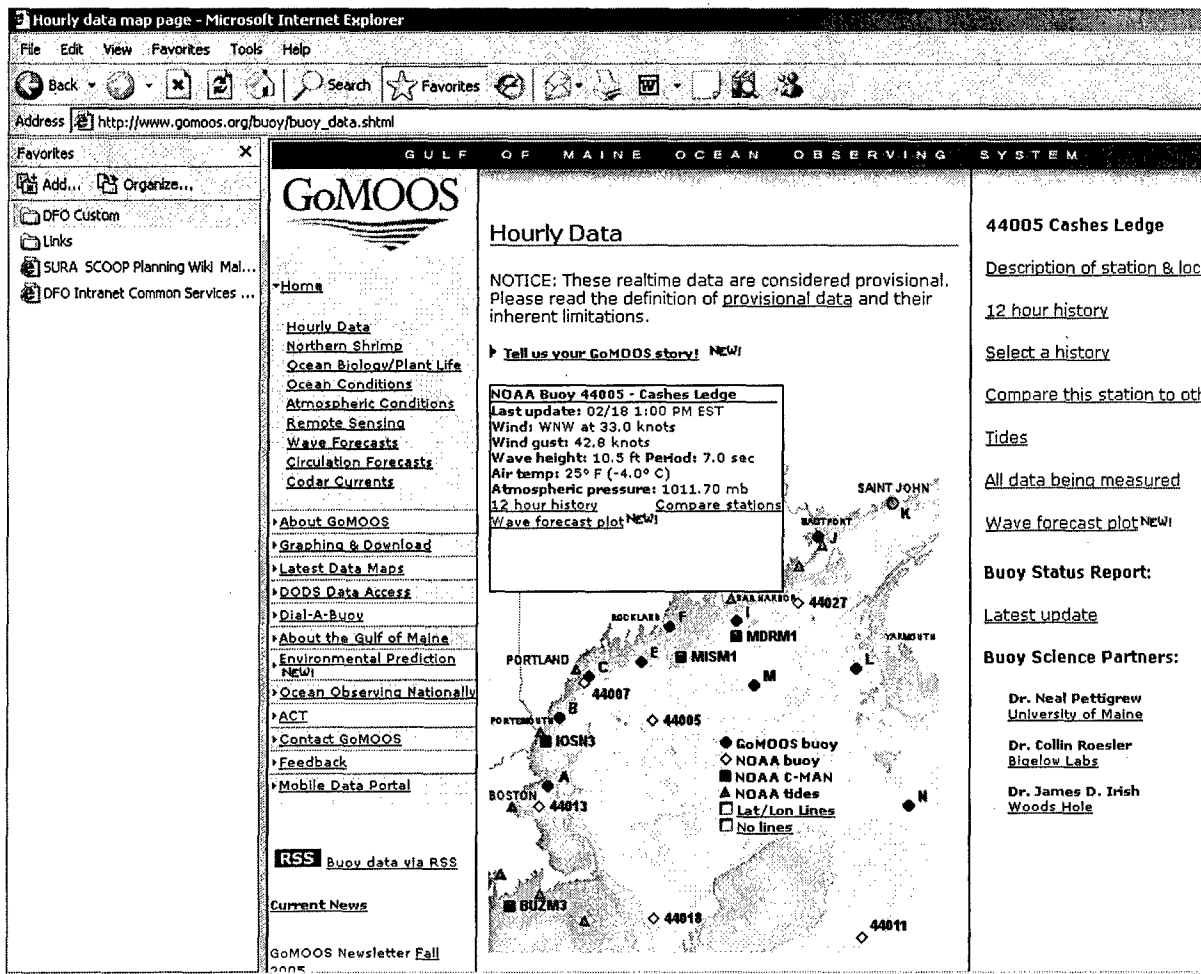


Figure 1(c) Fine resolution (0.2°) domain for the operational SWAN forecasts.



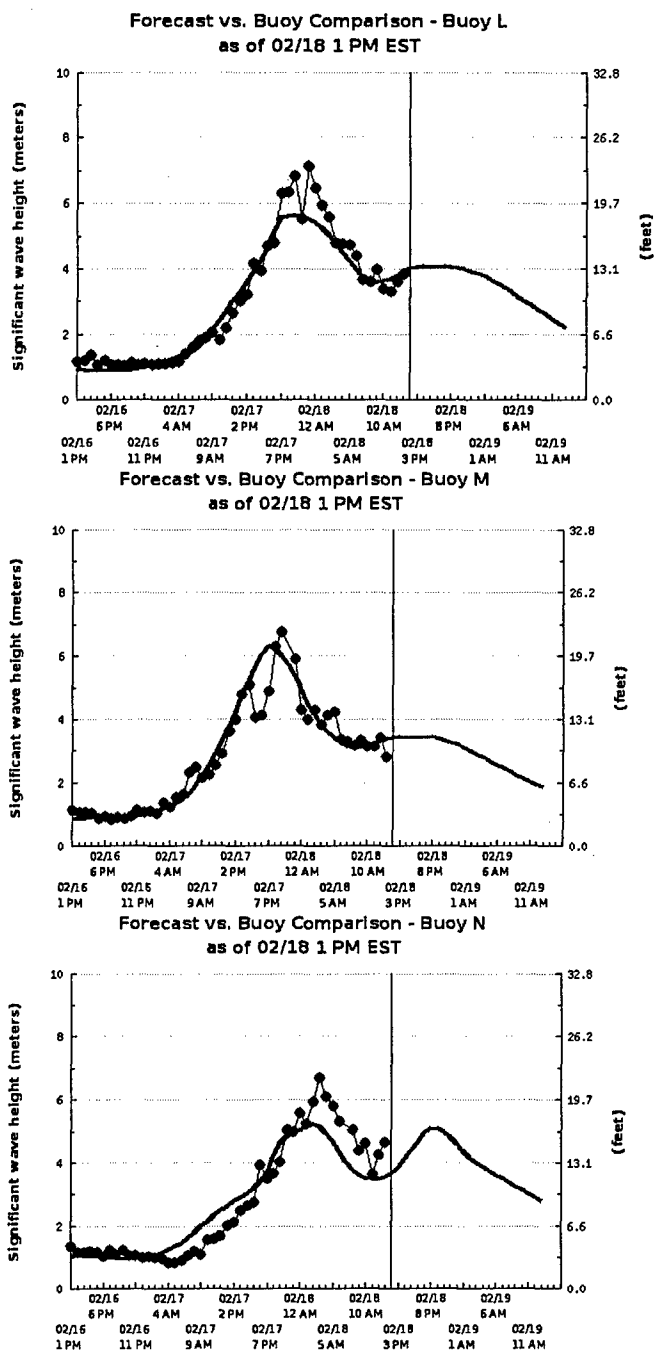
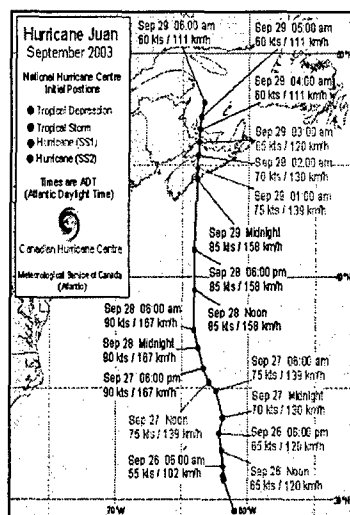
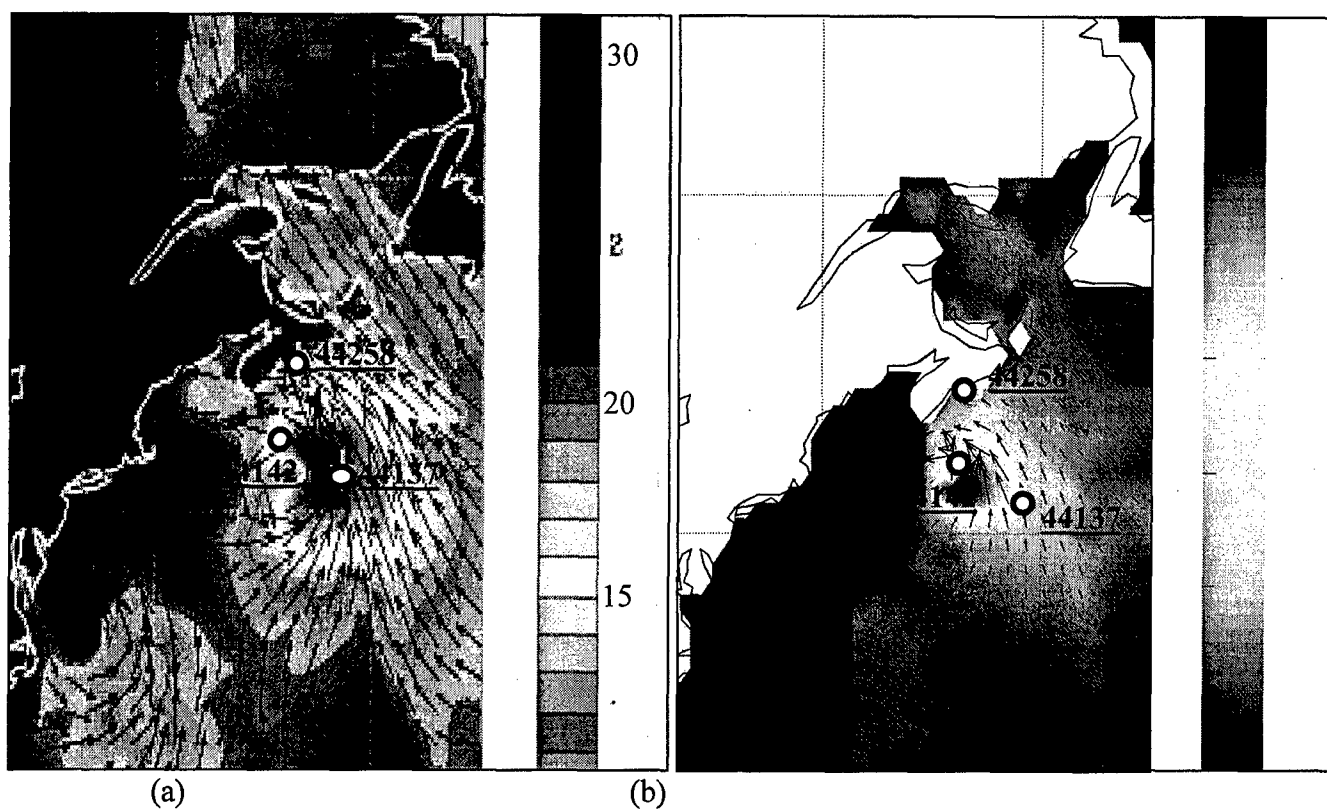


Fig. 3. Comparisons between forecasted wave height (—) and observed data (—●—) at (a) buoy L, (b) buoy M, and (c) buoy N.



(c)

Figure 4. Comparison of wind fields: (a) COAMPS winds at 00 UTC on 29 September, (b) blended scatterometer winds from 18-24 UTC on 28 September, and (c) CHC storm track analysis and peak storm winds. MSC buoys are 44142, 44137, and 44258 as indicated. Wind speed units are m/s.

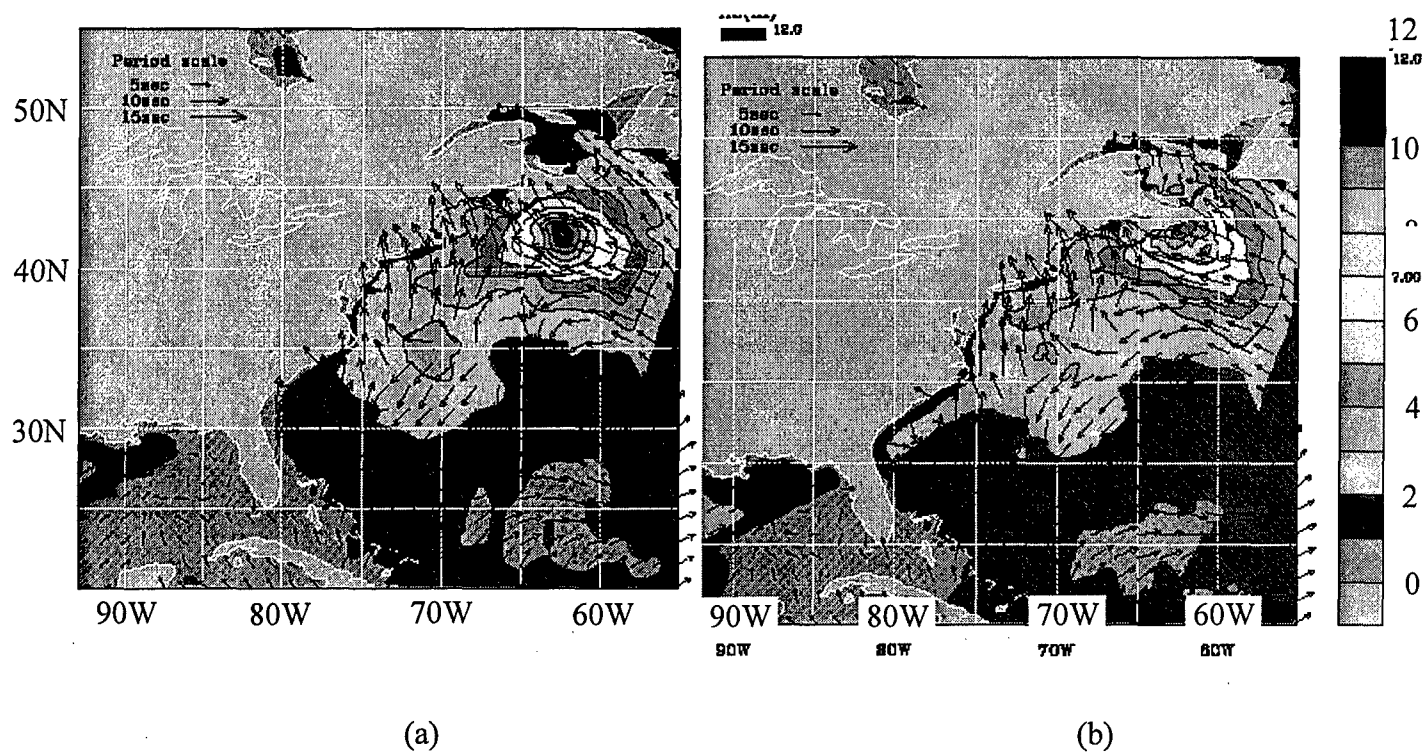


Figure 5. WW3 wave model outputs for (a) 12-h and (b) 18-h forecasts, based on GoMOOS run at 12 UTC on 28 September. These forecasts, valid for 00 UTC and 06 UTC 29 September, respectively, indicate the peak wave heights for Juan occurred in the early hours of 29 September. Significant wave heights (contours), wave directions (arrows), and wave periods (length of arrows) are shown. Wave height units are m.

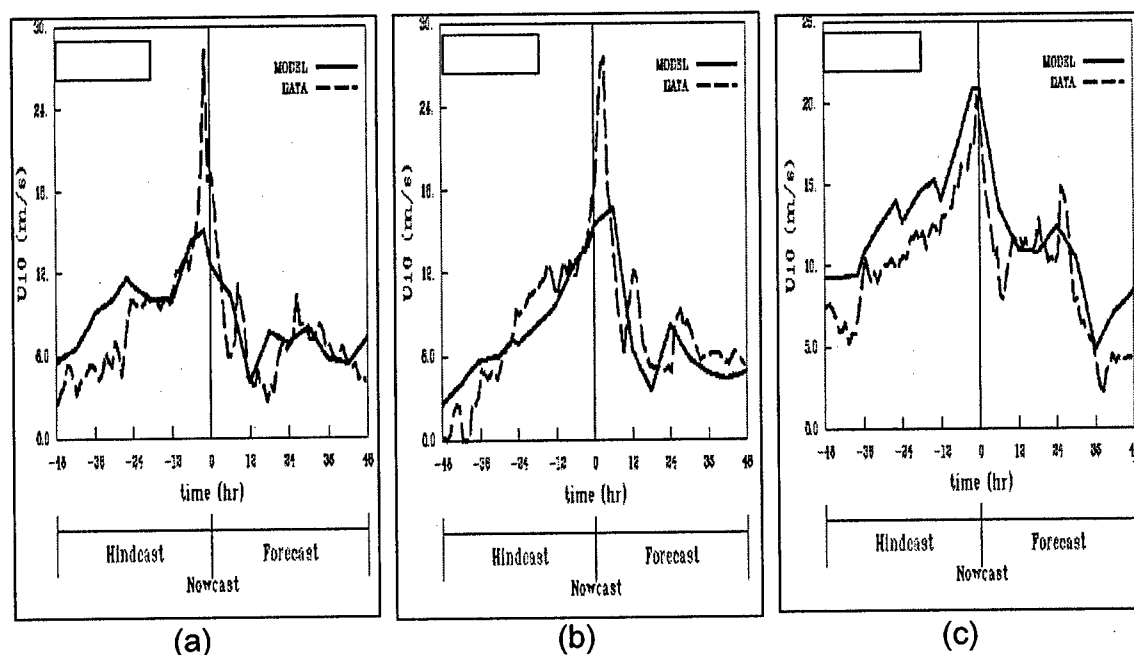


Figure 6. Comparison of COAMPS wind forecasts (—) from operational MSC buoys (a) at the mouth of Halifax Harbour (44258), and on Scotian Slope (b) buoy 44142 and (c) buoy 44137, and for observed (---) 10-m wind speed (U10). Routine forecasts are plotted every 12h, from hindcasts ($-48 \leq t < 0$ hr), nowcast ($t=0$), and forecasts ($0 < t \leq 48$ hr) for each buoy.

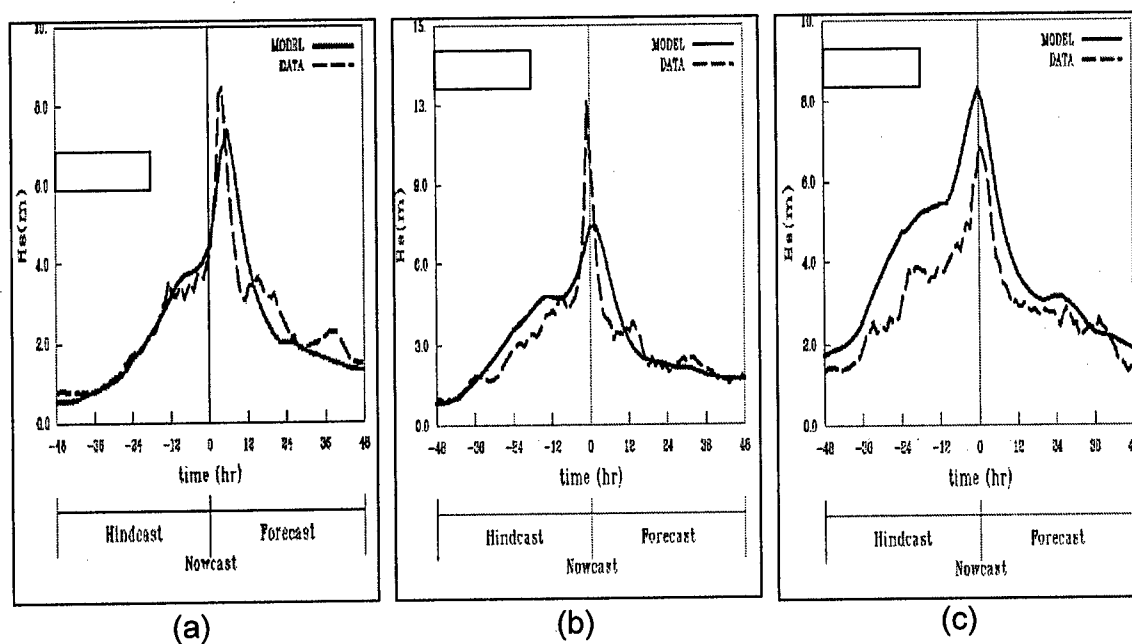


Figure 7. Comparison of wave model forecasts with observations from buoys (a) 44258, (b) 44142 and (c) 44137, for significant wave height (H_s), during Hurricane Juan. Routine forecasts (—) are plotted every 12h, from hindcasts ($-48 \leq t < 0$ hr), nowcast ($t=0$), and forecasts ($0 < t \leq 48$ hr), compared to observed data (---).

Nutrient Monitoring - GoMOOS – Final Progress Report

David W. Townsend, Maura Thomas, and Megan Schiff, University of Maine

Introduction

The following report summarizes work performed over the past three years (from July 2002 to October 2005) by Townsend's biological oceanography laboratory in the School of Marine Sciences at the University of Maine, as part of the GoMOOS award to the University. Our proposed activities included the analyses of inorganic nutrients in and around Casco Bay, and to develop techniques for using the WS Enviro Tech, EcoLAB *in situ* nutrient analyzer.

Casco Bay Nutrient Collections and Analyses

A total of 2,259 water samples have been collected and analyzed between 2002 and 2005. The samples were collected at stations in Casco Bay (Fig. 1) and analyzed at the University of Maine for dissolved inorganic nutrients (nitrate plus nitrite, silicate, phosphate and ammonium). The samples are continually being collected by the non-profit organization "Friends of Casco Bay", as part of a direct subcontract with GoMOOS. Water samples are collected and frozen for later analyses at the University using a Bran+Luebbe AutoAnalyzer III and standard methods. As soon as the samples are processed the results are posted in both tabular and graphical formats for easy access at the following website: <http://grampus.umeoce.maine.edu/gomoos/stnmap.htm>.

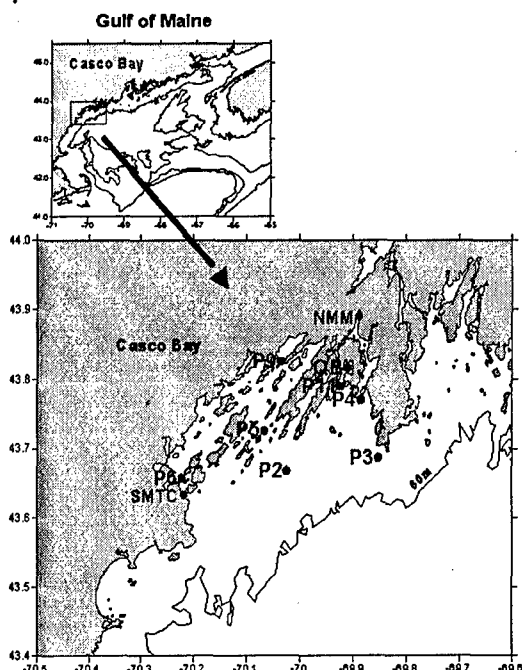


Figure 1. Location of Casco bay and sampling stations occupied by Friends of Casco Bay



Figure 2. EcoLab 4-channel nutrient analyzer undergoing calibration and sensitivity experiments in Townsend lab

EcoLAB in situ Nutrient Analyzer Laboratory Calibration Experiments

Calibration experiments continued over the past years with the EcoLAB, which is the multi-channel nutrient analyzer developed by WS Enviro Tech (Fig. 2). Two units were purchased by GoMOOS. They were each equipped with two colorimeters, one to measure the concentration of nitrate and the other to measure silicate and phosphate. Ammonium sensors were shipped much later. Efforts continued over the past three years to work out analytical problems associated with initial design flaws in the instrument. For example, we learned that the ammonium detectors were released prematurely from the company without satisfactory calibration; the detectors were returned to WS Enviro Tech, and the company continues to work on the problem. We then made improvements in the precision of nitrate measurements by switching to the "Open Tubular Cadmium Reactor (OTCR)" which is manufactured by Irama Corporation in Oregon; our nitrate Residual Standard Deviation (RSD) now varies between 3% and 7%. The phosphate detectors were also sent back to Enviro Tech for further testing because of our continued failure to remove erratic laboratory calibration results. The units were subsequently returned to us with new intensity settings, revised scripts and reagents. RSD of phosphate is now approximately between 3% and 5%. The silicate method continues to produce reliable and accurate results (RSD = 1% to 3%). We analyzed data collected in the spring of 2005 by the moored sensors after they were deployed in a short-term test (10 days) off the dock at Southern Maine Community College in South Portland. The result of that test deployment convinced us this past summer and fall that these units would not be useful to the GoMOOS Mooring program, in that their reliability and duty time (ca. 2 weeks) were both inadequate.

Progress/Recommendations

We recommend the following:

1. GoMOOS should continue to collect and analyze nutrients in Casco Bay; this database is the first of its kind in the Gulf of Maine region. Now five years long, this time series will be invaluable to resource managers and scientists as it continues and as patterns become revealed (e.g., see Fig. 3). That these data are now, and will continue to be valuable, has been especially true this past year, during which the Gulf of Maine witnessed one of the worst outbreaks of Paralytic Shellfish Poisoning in recent decades. This past year was also unusual in that the Gulf's waters were unusually fresh and low in nutrients in the offshore regions (based on a research cruise conducted independent of this project). It remains to be seen just how these events are reflected, and explained by, the measurements we have made and continue to make in Casco Bay.
2. We should discontinue developing the EcoLAB analytical capabilities. We propose that GoMOOS instead look to the ISUS (In-Situ Ultraviolet Spectrophotometer) Nitrate sensor for deployments on moorings, and that we explore developing new sensors in partnership with the Sensor Development group in the University of Maine's Laboratory for Surface Science and technology.

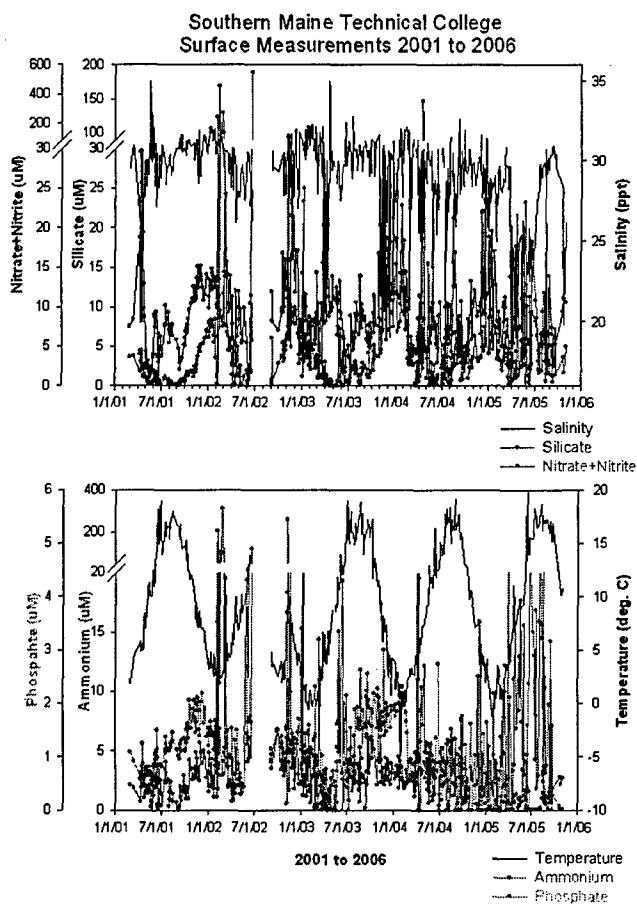


Figure 3. Five-year time series of data collected at the SMTC Station (the dock at Southern Maine Community College).